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Postcranial Osteometric Assessment of Korean Ancestry

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POSTCRANIAL OSTEOMETRIC ASSESSMENT OF KOREAN ANCESTRY

by

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ABSTRACT

The determination of ancestry is an important part of an individual's identification when creating a biological profile. This thesis scrutinizes postcranial variation using over 65 osteometric sorting measurements in an attempt to identify those measurements that display the most significant differences among Koreans, Africans, and Europeans. Data was collected from four American skeletal collections and one South Korean skeletal collection for a total sample population of 306 individuals: 24 of Korean ancestry, 66 of African ancestry, and 216 of European ancestry. In an effort to minimize the number of measurements needed for ancestral assessment, stepwise discriminant analysis was performed for measurements of each skeletal region and region combinations. Initial findings highly misclassified Africans, so the results of this study were separated into two parts: Koreans from Africans/Europeans and Africans from Europeans. A majority of the functions developed in the first part of the analysis resulted in cross-validated classifications of 80% and greater for Koreans and 77% or greater for Africans/Europeans with the highest classifying function for both ancestral groups being composed of upper limb measurements. Most of the discriminant functions from the second part of the analysis correctly differentiated Africans with 70% or greater accuracy and Europeans with 72% or greater accuracy with the highest classifying function for both groups consisting of pelvis, lower limb, and foot measurements. These functions indicate that ancestry can be determined successfully from postcranial elements; that certain skeletal regions are better indicators of ancestry than others; and that osteological remains do not need to be complete to develop an informative biological profile.

ACKNOWLEDGEMENTS

I owe a great deal to my thesis committee. My advisor and thesis committee chair, Dr. Tosha Dupras, for her willingness to allow me to pursue this research and believing me to be competent enough to come back with meaningful data. I could not have asked for a better advisor during my graduate career at UCF. Dr. John Schultz, for his critical eye which has helped me to refine my work and create a better "end result" of which I can be proud. Dr. Matthew McIntyre, for all his patience and statistical assistance. Dr. John Byrd, for the use of his European and African ancestry data for this thesis. His guidance and expertise has been very valuable to the correct collection of osteometric sorting measurements as well as the formation of this thesis topic.

Additionally, the Joint POW/MIA Accounting Command Central Identification Laboratory (JPAC CIL) was kind enough to provide me an opportunity to refine my measurement skills during my stay in Hawaii in their laboratory and lend me calipers for data collection. I am especially grateful to Professor Sunjoo Park of Chungbuk National University, who gave me access to the Goyang collection and was very hospitable to all my needs during my stay in Cheongju, South Korea. Without his flexibility, I would not have been able to complete my research. And Dr. Jennie Jin, for helping me to make contact with Professor Park and for assisting me with the translation of Goyang collection papers.

Lastly, I would like to thank my parents, Jeffrey and Teresa "Teri" (Wynn) Okrutny, for their never-ending support in all my endeavors. I couldn't have done this without them.

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CHAPTER ONE: INTRODUCTION

Developing a biological profile is an important task in the identification of skeletal remains, which can be made more difficult when the skull is missing (Duray et al., 1999; Wescott, 2005). This is particularly true when an anthropologist is attempting to determine an individual's ancestral origins, as morphological and metric cranial traits are most commonly used and believed to be the most accurate (Duray et al., 1999; Holliday and Falsetti, 1999; Bass, 2005). In an effort to better assess ancestry, postcranial methods need to be applicable to a diverse spectrum of skeletal elements (Wescott, 2005). Morphological methods have popularly focused on the femur, and osteometric analyses of postcranial measurements often require complete bones for any measurements to be collected (Dibennardo and Taylor, 1983; İşcan, 1983). More techniques are needed to evaluate ancestry from other postcranial skeletal elements with a minimal number of measurements, while still being high predictors and applicable when remains are fragmentary (İşcan and Cotton, 1990; Marino, 1997). This study is designed to further explore the potential usefulness of postcranial measurements in the assessment of ancestry and highlight skeletal elements that are the most useful in classification.

The goal of this study is to determine if ancestry can be ascertained using postcranial osteometric sorting measurements, and if so, which ones are the most useful in differentiating groups. Most studies compare African to European ancestry (Terry, 1932; Dibennardo and Taylor, 1983; İşcan, 1983; Taylor and Dibennardo, 1984; Baker et al., 1990; İşcan and Cotton, 1990; Craig, 1995; Marino, 1997; Duray et al., 1999; Holliday and Falsetti, 1999; Trudell, 1999; Kindschuh et al., 2012) or Native American ancestry to a pooled population of African and European ancestry (Gilbert, 1976; Gilbert and Gill, 1990; Wescott, 2005; Wescott, 2006;

Wescott and Srikanta, 2008). This study is unique in that it examines differences in the three main ancestral groups through a two-part analysis using postcranial measurements from four American collections and a South Korean collection. It has been suggested that Asians closely resemble Native Americans enough for a correct classification to be rendered when compared to African and European ancestry using certain postcranial methods (Wescott and Srikanta, 2008), but little attention has been paid to individuals from continental Asia. Ideally, an ancestral study would have multiple populations representing a geographical ancestry, but it is challenging to find large collections of skeletons of Asian ancestry as their limited presence in the United States in the past was restricted by immigration regulations (Perez and Hirschman, 2009). As judicial action has since lifted these regulations, immigration from Asia to the US has increased (Perez and Hirschman, 2009), making the inclusion of this ancestral group in anthropological studies and forensic cases important (Byers, 2008). This is one of the first studies to include an analysis of an Asian ancestral population other than Native Americans conjointly with African and European ancestral populations.

This study is focused on the metric examination of postcranial ancestry using osteometric sorting measurements originally developed to assist anthropologists in the sorting of commingled remains (Byrd and Adams, 2003). Because the measurements focus on morphological landmarks, minimum and maximum diameters, and minimum and maximum breadths, complete bones are not necessary for assessment. This is particularly useful when faced with fragmentary remains, as applicable measurements still can be gathered to assess ancestry and further build a biological profile of the individual. Additionally, these measurements are advantageous in that they can be collected on all postcranial bones except for the ribs, sternum, vertebrae, coccyx, and phalanges. Since this study will also assess the measurements most beneficial in ancestral assessment for each region as well as the measurements with the greatest discriminatory power between ancestral groups, it will be helpful in situations where remains may only have bones from a particular region of the postcranial skeleton.

Chapter Two presents a literature review of previous postcranial ancestry studies that have or are currently being used to postcranially predict ancestry. Prior research has overwhelmingly focused on African and European ancestry (Terry, 1932; Dibennardo and Taylor, 1983; İşcan, 1983; Taylor and Dibennardo, 1984; Baker et al., 1990; İşcan and Cotton, 1990; Craig, 1995; Marino, 1997; Duray et al., 1999; Holliday and Falsetti, 1999; Trudell, 1999; Kindschuh et al., 2012) or Native American ancestry against a pooled group of African/European ancestry (Gilbert, 1976; Gilbert and Gill, 1990; Wescott, 2005; Wescott, 2006; Wescott and Srikanta, 2008). Most of the studies examined in this review focus on the femur and pelvis (Gilbert, 1976; Dibennardo and Taylor, 1983; İşcan, 1983; Taylor and Dibennardo, 1984; Baker et al., 1990; Gilbert and Gill, 1990; Craig, 1995; Trudell, 1999; Wescott, 2005; Wescott, 2006; Wescott and Srikanta, 2008) while a few have noted ancestral variation in the cervical vertebrae (Marino, 1997; Duray et al., 1999), hyoid (Kindschuh et al., 2012), and clavicles (Terry, 1932). Of the femoral studies published, a majority have determined that American Indians, and presumably Asians, are on average more platymeric than individuals of African or European ancestry, but that statistically no differences can be drawn between Africans and Europeans using the platymeric index (Wescott and Srikanta, 2008). Other postcranial methods that compare just European and African ancestry have significant differences in metric and morphological traits, but possibly due to the heterogeneity of the African American population, African individuals are the most likely group to misclassify (Duray et al., 1999; Trudell, 1999). This study attempts to assess all three ancestries using the same measurements and statistical analyses so that the same method can be applied to remains when no particular ancestry is predicted.

Chapter Three consists of the materials and methods of this study. A total of five skeletal collections were utilized, and the background of each is elaborated upon as well as the sample size of each ancestral population drawn from a particular collection. Over 50 osteometric sorting measurements were amassed for each individual included in the study and can be found listed in Chapter Three. Each measurement is grouped by the skeletal element from which it is taken. A brief description of statistical analyses of the data is also presented.

Discriminant function analysis is used for the shoulder girdle and upper limbs, hands, pelvis, lower limbs, feet, and combinations of these body regions. By using discriminant analysis, it will be easier to expose variation between ancestral groups and minimize the measurements needed to predict classification while maintaining a high accuracy. Since analysis will produce functions from measurements of select skeletal regions, it is possible to assess the degree of ancestral variation of different parts of the body. Chapter Four presents the results of each discriminant analysis while highlighting the functions and measurements that best classify postcranial bones. Initial analyses of these data had high misclassification when all three ancestral groups were examined, so this chapter is broken into two parts: differentiating Korean from African/European and differentiating African from European. A discussion of the results can be found in Chapter Five, while conclusions, limitations, and future considerations are found in Chapter Six.

CHAPTER TWO: LITERATURE REVIEW

The biological profile consisting of age, sex, ancestry, and stature is an important component in the positive identification of human remains. Of the four major aspects, ancestry is the most controversial and difficult to assess (Duray et al., 1999; Byers, 2008; Sauer and Wankmiller, 2009). Historically, many different academic terms and cultural vernacular have been used to describe people based on their visual similarities and differences. During the late 1800s and early 1900s, anatomists classified remains into social racial categories on the basis of the texture of an individual's hair and by the color of their skin (Wedel, 2007). This visual assessment of the soft tissue was then applied to the osteological elements of the individual when they were gathered for skeletal collections despite the possibility that they may not correspond to one another (Duray et al., 1999; Wedel, 2007; Byers, 2008).

"Race" is a social category that has been used by the government to distinguish between individuals of various phenotypes (St. Hoyme and İşcan, 1989; Byers, 2008). While race is based on observable biological differences, the populations that it categorizes are not genetically discrete (Duray et al., 1999; Wedel, 2007; Byers, 2008). Many of the traits accepted as being strong predictors of a particular racial group have more genetic variation than originally thought as populations have more variation within themselves than between other populations due to gene flow between adjacent regional groups (Brace, 1995; Hefner, 2009).

Specific traits have manifested in different geographical groups through the continuity of certain regional traits in world populations. These geographical ancestries are "regional clusters of populations [that] owe the similarities in their appearance to the perpetuation of traits that are shared by virtue of kinship but which have no other biological significance" (Brace, 1995:173).

Anthropological methods identify these ancestral similarities when building a biological profile, but as the missing persons reports submitted to the police identify individuals based on their social race, forensic anthropologists often have to equate geographical ancestries to current racial categories (St. Hoyme and İşcan, 1989; Wedel, 2007; Byers, 2008). Thus, all authors refer to racial classification in the publications of their techniques. For consistency in this thesis, as racial terms have evolved over time, individuals of mainly European ancestry will be referred to as White, individuals of mainly African ancestry will be referred to as Black, and individuals of mainly Asian ancestry will be referred to as Asian or Native American depending on the geographic location with which the population is associated.

Ancestry has commonly been assessed using cranial traits with many deeming it to be the most accurate element of the skeleton for accurate determination (Duray et al., 1999; Bass, 2005; Ousley et al., 2009). Most assessments predict group affinity based on morphological, nonmetric characteristics, or cranial osteometric points. Traditional nonmetric analysis involves the visual assessment of the skull, listing specific morphological characteristics and the likelihood that the individual is of a specific ancestry (Hefner, 2009). Many of the cranial traits allow for differentiation between two of the main ancestral groups but are unable to distinguish all of them which has led to the creation of extensive characteristic lists for evaluations (Rhine, 1993; Hefner, 2009). While efforts are being made to standardize morphological traits, the discovery of new traits and the development of new trait combinations would add more value to this method (Hefner, 2009).

Craniometric measurements and discriminant functions have been used as a more standardized and repeatable method of ancestry determination (Giles and Elliot, 1962). Various studies have examined regional and continental populations and present strong evidence of geographic patterns (Ousley et al., 2009). One of the most well-known statistical tools for craniometrics is FORDISC, a program that calculates the best ancestral fit for a particular cranium based on comparison between its measurements and those of 11 reference groups included in the program sample (Burns, 2007; Sauer and Wankmiller, 2009). Anthropologists can assess the probability of group membership and the degree to which it fits with the other reference skulls of the database by examining the posterior probability and typicality listed with the results (Burns, 2007).

Assessment of ancestry is more challenging when the skull is unavailable or incomplete (Wescott, 2005; Byers, 2008). In such cases, anthropologists must use analyses specific to postcranial bones to determine ancestry for the biological profile. Of all the postcranial elements, the femur is by far the most researched for ancestry (İşcan, 1983; İşcan and Cotton, 1990; Wescott, 2005; Sauer and Wankmiller, 2009) with numerous analyses developed to examine the discriminatory value of anterior curvature, subtrochanteric shape, and intercondylar notch morphology. Each technique looks at a different region of the femur and has its own classification accuracy. While requiring complete or near complete femora for accurate analysis, the metric determination of anterior femoral curvature has been found to be useful in distinguishing racial groups (Stewart, 1962; Walensky, 1965; Gilbert, 1976; Trudell, 1999).

Initial research on anterior femoral curvature was prompted by comments made by Aleš Hrdlička to T. Dale Stewart (1962) while discussing the morphological differences in long bones. Finding no formal method supporting his mentor’s observations, Stewart metrically compared the expression of anterior curvature in American Blacks, American Whites, and Native

Americans of the Dakotas, establishing that femoral curvature was found in combination with pronounced femoral torsion and the greater the curvature the more significant the torsion (Stewart, 1962; Gilbert, 1976; Byers, 2008). This curvature was greatest in the Native American sample and minimal in the American Black individuals while the American Whites fell in-between the two extremes (Stewart, 1962; Walensky, 1965; Gilbert, 1976). While the population means suggested ancestral differences, the newly developed technique was able only to separate Native Americans from American Blacks and American Whites with statistical significance and left many questions unanswered as to the cause of this morphological trait (Gilbert, 1976; Trudell, 1999).

Further research of anterior curvature ensued soon after by Walensky (1965) with the addition of an Inuit sample to Stewart's original three population groups in an effort to understand better the variation attributed to sexual dimorphism and siding. Both were found to have no significance, but a positive correlation emerged between age and curvature (Walensky, 1965). This prompted the hypothesis that anterior femoral curvature could be the result of a combination of genetics and environment (Walensky, 1965; Gilbert, 1976). With age comes an increase in body weight, and obese individuals have a more anterior center of gravity, further supporting that the genetic basis for curvature has some plasticity (Gilbert, 1976).

The significance of equestrian practices, temporal change, clinal differences, and postural habits determined by culture were soon ruled out by Gilbert (1976) in his examination of seven additional Native American samples that span from the pre-Columbia era to post contact in both North and South America. All effects were determined to be insignificant: equal or greater curvature was found in nonequestrian societies, modern and historic samples of similar areas had the same curvature, populations in the same location can have as great a difference in curvature as those in different geographical clines, and similar cultures were not found to share similar curvature (Gilbert, 1976).

The analysis of subtrochanteric shape through the platymeric index has been found to reliably classify non-Native American individuals from Native Americans with complete and fragmentary femora (Gilbert and Gill, 1990; Wescott, 2005; Wescott, 2006; Bass, 2005). Native Americans consistently have a greater subtrochanteric mediolateral diameter in comparison to their anterior-posterior diameter classifying them as platymeric while American Blacks and American Whites are most often eurymeric (Wescott and Srikanta, 2008). This trait was originally believed to be highly heritable as there has been no observable temporal change in Native American populations for over 300 years (Gilbert and Gill, 1990); however, environment and biomechanics could play a large part in group variation (Wescott, 2006).

From birth to five years of age, the diameter of the femur increases more rapidly mediolaterally than it does anterior-posteriorly, especially in Native American children (Wescott, 2006). This rapid growth rate of the early years decreases but continues gradually from age six until complete ossification of the metaphyseal plates occurs (Wescott, 2006). It is during this first five years of life that the femur is subjected to changing biomechanical stress as the individual learns to walk (Wescott, 2006). Having shorter femora in relation to their hip breadth, Native Americans tend to have greater mediolateral stress when developing a mature gait in comparison to American Blacks and Whites in the same age group which leads to more rapid bone disposition along this plane (Wescott, 2006). Due to this early establishment of adult subtrochanteric shape, it is possible to reliably classify femora using Gilbert and Gill's (1990) sectioning point for anterior-posterior diameter and mediolateral diameter in subadults as young as nine years of age (Wescott, 2006).

Few measurements are required to observe ancestral differences, but analyses should be carried out with caution as some assumptions have been made in the creation of racial sectioning points. The subtrochanteric measurements themselves have a significant amount of intra- and interobserver error regardless of experience level (Adams and Byrd, 2002; Wescott and Srikanta, 2008). Native Americans are not a genetically homogenous population, and as such, they display different levels of platymeria (Wescott, 2005). While the within-population range of individual variation in proximal femoral size and shape is considerable, the platymeric index makes it difficult to separate based on specific populations, but all studies conclude that individuals with Asian ancestry are more platymeric than their European or African ancestry counterparts (Wescott and Srikanta, 2008).

Measurements of the maximum height of the intercondylar notch have been shown to differentiate American Whites and Blacks when the femora are complete or in samples where the original diaphyseal curvature has been preserved (Baker et al., 1990). Notch height can be calculated by placing the femur on a flat surface and measuring the distance from the surface the bone is resting upon to the "most superior point of the anterior outlet of the intercondylar notch" (Baker et al., 1990:92). The measurement has been shown to be influenced by sexual dimorphism and anterior curvature, so it is possible to determine sex and ancestry. Greater curvature in the diaphysis leads to smaller measurements and characteristic classification as White while those with larger measurements classify as Black (Baker et al., 1990; Craig, 1995). Classification of ancestry is determined by sectioning points which are specific to the sex of the individual under analysis (Baker et al., 1990). No significant variation was found when testing the method on the right and left femora so either can be used for ancestral analysis (Baker et al., 1990).

These differences in height have also been theorized to be due to differences in the intercondylar shelf angle, an angle radiographically determined by two landmarks: Blumensaat's line and the posterior cortex of the distal femur (Craig, 1995; Berg et al., 2007). A more acute angle creates a higher intercondylar notch and conversely an obtuse angle forms a lower notch. Similar to the results from the maximum notch height analysis, Whites with smaller measurements have more obtuse intercondylar shelf angles and Blacks with larger measurements have more acute shelf angles (Craig, 1995). The benefits of this method are that it can be completed on fragmentary femora, can be taken in femora with pathological conditions or trauma, and is not hindered by the presence of soft tissue (Craig, 1995). However, despite claims by the method's author, significant error has been identified in this method as the "best-fit" line through Blumensaat's line and the line along the posterior cortex of the distal femur is subjective when dealing with cases of high diaphyseal curvature (Berg et al., 2007). This does not make it a poor method for classification, but it does highlight the need for more refinement and standardization.

The pelvis has often been referenced for its discriminatory power in sex determination (Taylor and Dibennardo, 1984; Albanese et al., 2008; Gómez-Valdés et al., 2011; Plochocki, 2011), but it also has merit in ancestry determination (İşcan, 1990). The transverse and biiliac diameters of an articulated pelvis are less affected by environmental factors, such as nutrition and socioeconomic status, which makes them more powerful in ancestry determination (İşcan, 1983). While requiring complete innominates and sacrum to gather measurements, the number of measurements is minimal and the classification accuracy of the technique is over 80% for both sexes (İşcan, 1983). The greater sciatic notch and acetabular area of the innominates, in contrast, are highly resistant to damage and more likely to be available for analysis in fragmentary pelves (Taylor and Dibennardo, 1984). Having high sexual and ancestral prediction, discriminant function analyses attribute the main difference between Blacks and Whites to size, with Whites having: larger notch height, notch position, and acetabular diameter measurements (Taylor and Dibennardo, 1984).

The upper axial skeleton is not as well researched in relation to ancestral variation as the femur and pelvis, but it does show some promise in the differentiation of African and European ancestry (Marino, 1997; Duray et al., 1999; Kindschuh et al., 2012). The width of the right inferior facet of the first cervical vertebra and the maximum distance between its left and right inferior facets have been found to differ constantly between Whites and Blacks (Marino, 1997). Alone, atlas measurements can classify with 60-70% accuracy, but in combination with measurements of the basicranium, the accuracy jumps to between 70-90% (Marino, 1997). Additionally, the morphology of the spinous processes of C3-C6 demonstrates significant differences in bifidity among ancestries and between the sexes (Duray et al., 1999). Racially, Whites have a higher frequency of bifidity while Blacks tend to have a greater nonbifidity which is most evident in C3 and C4 (Duray et al., 1999). This could lead to a high classification probability if both vertebrae are bifid or nonbifid, but it makes the combination of one bifid vertebra with a nonbifid vertebra problematic as this interaction of vertebral levels has not been tested (Duray et al., 1999).

The isolated hyoid, which can be found fused or unfused depending on the individual, has correctly classified over 70% of American Whites and Blacks (Kindschuh et al., 2012). The morphological variations in size and shape are surmised to be linked to the degree of prognathism produced in the mandible and mid/lower regions of the face in connection with muscle and ligament attachments (Kindschuh et al., 2012). By providing discriminant function equations for both the fused and unfused hyoid, this method has increased the applicability to forensic anthropologists and archaeologists working with fragmented modern or historical skeletal remains (Kindschuh et al., 2012).

Significant differences have also been found in the morphology of the clavicle relating to sexual dimorphism and ancestry. Most of the sexual differences can be made only in relation to individuals of African ancestry as White female comparison samples were lacking at the time of initial analysis (Terry, 1932). Out of over 10 measurements developed from visual observations, the acromial extremity of Black male clavicles were found to be significantly narrower than their White male counterparts and were more likely to have a smaller or often absent conoid tubercle (Terry, 1932).

A majority of postcranial studies center on a single skeletal element, many with significant results; but classification predictions can increase when skeletal elements are combined for analysis (İşcan and Cotton, 1990). The combination of the innominate with the femur or tibia has repeatedly resulted in higher classification, and this could be attributed, in part, to multivariate analysis numerically expressing ancestral differences in limb and torso proportions (Dibennardo and Taylor, 1983; Choi et al., 1997; Holliday and Falsetti, 1999). This proportional difference is more prominent in the long bones of males than in females (İşcan and Cotton, 1990).

Multiple methods for ancestry determination are necessary as the most common techniques or traits may be poorly suited to the analysis of fragmentary bones (Rhine, 1993; Marino, 1997; Wescott, 2005). As such, the assemblage of a wide spectrum of techniques for a variety of different bones could increase the chances of anthropologists accurately predicting ancestry (Marino, 1997; Wescott, 2005). This study will address the need for techniques that can be performed on complete and fragmentary bones without seriously sacrificing classification accuracy by focusing on morphological features and areas of the skeleton likely to remain intact.

The population of the United States keeps changing and diversifying. To keep up with this flux in demographic configuration, anthropologists need to continue fine tuning and developing methods that can correctly differentiate based on ancestral variation (Spradley et al., 2008; Kindschuh et al., 2012). Most techniques available for postcranial analysis allow for differentiation of American Whites from Blacks (Wedel, 2007) or the differentiation of Native Americans from a pooled population of American Whites and Blacks (Gilbert and Gill, 1990; Wescott, 2006). Individuals of Asian ancestry from East Asia first started arriving in the mid-1800s, and due to government legislation, their numbers remained small until the 1960s when all restrictions were lifted (Perez and Hirschman, 2009). As of 2000, almost 4% of United States population identified themselves as Asian, and of that population, over 70% were immigrants (Byers, 2008; Perez and Hirschman, 2009). This influx in Asian immigration will only increase as time goes on. The variable analyses in this thesis compare American samples of African and

European ancestry against a South Korean sample of Asian ancestry in hopes of further increasing applicability.

CHAPTER THREE: MATERIALS AND METHODS

Materials

The postcranial elements that were utilized in this study are subsets of five collections. All individuals of Korean ancestry are from the Goyang collection, currently located at Chungbuk National University in Cheongju, South Korea. The Goyang collection is composed of 89 individuals found during the construction of several apartment complexes in Samsong (삼송), Shinwon (신원), and Wonheung (원흥). All three building sites are parts of subdivisions within Deogyang (더강), a small suburb of the larger city of Goyang (고양), which can be seen in Figure 1. Goyang is located in Gyeonggi (경기), the South Korean province that surrounds the capital, Seoul, as can be seen in Figure 2. All of the human remains found at the three sites date to the latter part of the Joseon (조선) dynasty, which extended from 1637 to 1897 AD (Korea Institute of Prehistoric Culture, 2009). Not much documentation regarding the remains is available, but the individuals exhumed are believed to be part of the pyungmin (평민) (Korea Institute of Prehistoric Culture, 2009). Individuals denoted as pyungmin were members of the Korean middle or lower classes during the Joseon dynasty. As they were not part of the country's nobility, persons of this social group were often buried in public cemeteries. Both males and females can be found within the collection ranging from 18 to over 60 years of age at the time of death (Korea Institute of Prehistoric Culture, 2009). Remains from the Goyang collection were chosen based on relative completion of the postcranial skeleton and an absence of trauma or pathology. Twenty-four individuals met the above criteria and were used for all of the following Korean ancestry analyses.

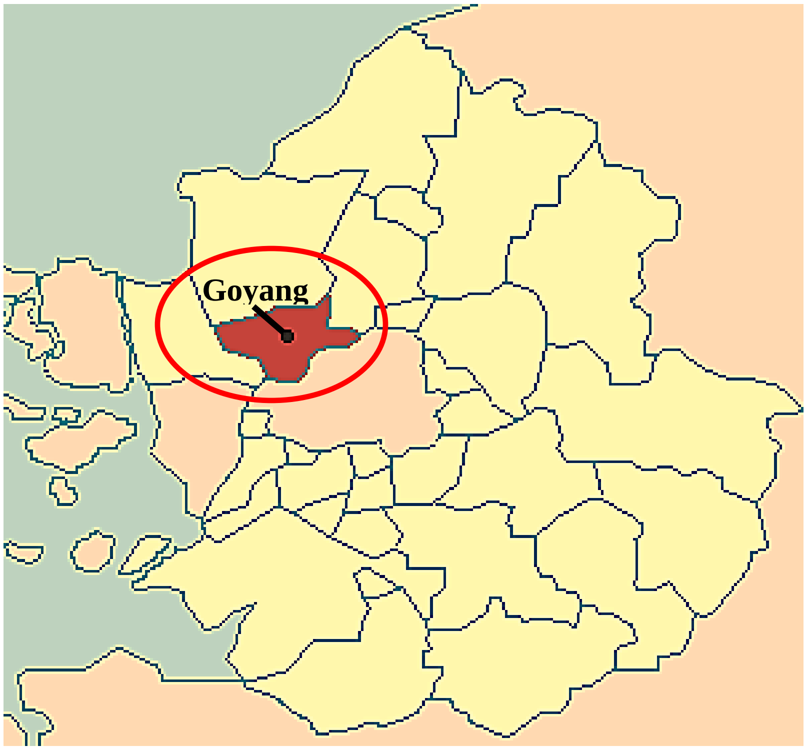

Figure 1. Location of Goyang within Gyeonggi province.

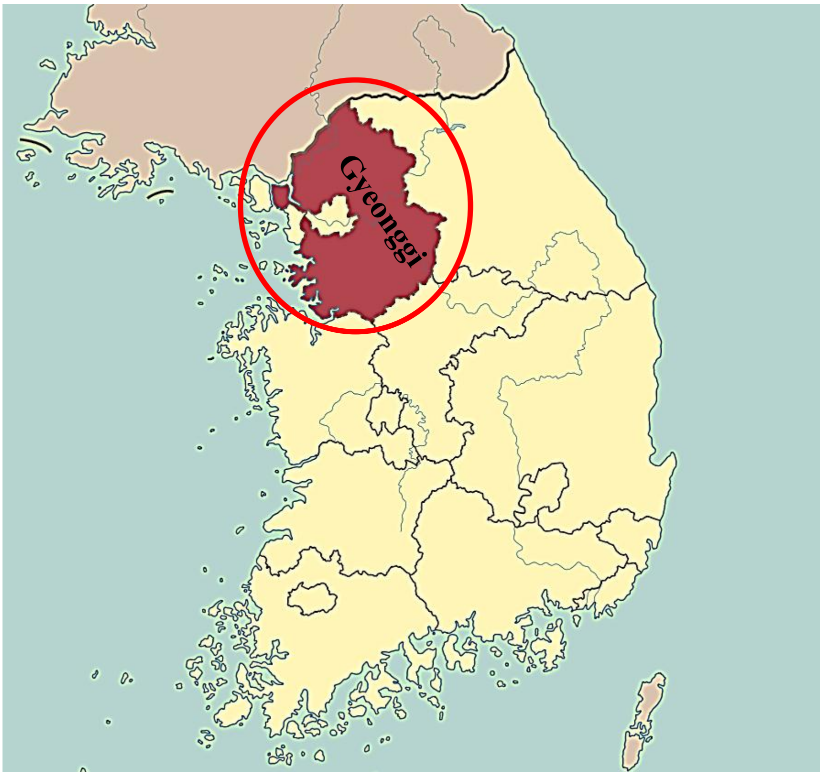

Figure 2. Map of South Korea provinces.

Data from the Terry collection, Hamann-Todd collection, JPAC CIL collection, and the Bass collection was assembled by Dr. Bradley J. Adams and Dr. John E. Byrd and has been used to represent a sample population of African and European ancestry. Additional postcranial data provided by Dr. R. Jantz to Adams and Byrd from the Forensic Anthropology Data Bank (FDB) was combined with the Bass collection remains as both are located at the University of Tennessee and no differentiation was made in the dataset between sample sources (Byrd and Adams, 2003). The selection criterion of postcranial remains for data collection was the same as that used for data collection of the Goyang collection: individuals were relatively complete and displayed no trauma or pathologies. The current sample is not an exact composition of that used in the publication of *Osteometric Sorting of Human Remains* (Byrd and Adams, 2003) as only individuals with data entries listing specific identification numbers from the collection from which they were selected were used to make it easier to locate the remains should further analysis be required. All data from the FDB and JPAC-CIL were scrubbed by Byrd and Adams (2003) for errors, and corrections were made accordingly.

To help visualize the number of individuals selected from each skeletal collection as well as their ancestral distribution, sex distribution, and age ranges, a series of figures were created. Figure 3 displays the distribution of individuals from all five collections, and Figure 4 displays the distribution of African ancestry individuals and European ancestry individuals from the four American collections: Robert T. Terry collection, Hamann-Todd collection, Bass collection, and the JPAC CIL collection. The sex distribution of the Goyang collection can be found in Figure 5, while the distribution of the American collections can be found in Figure 6 with the males and females separated based on African or European ancestry. Lastly, Figure 7 separates each collection sample by age ranges with the youngest category containing individuals listed as 19 years old or younger and the oldest category being 60 years old or greater. A number of individuals did not have a listed age or age range so they have been grouped as unlisted.

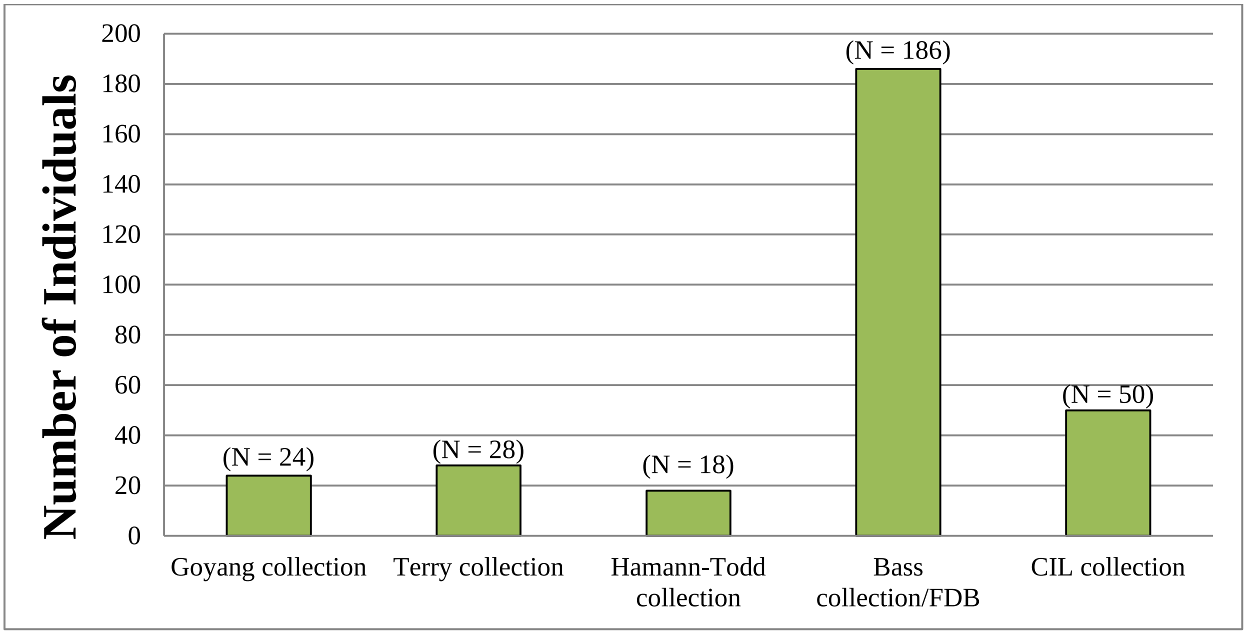

Figure 3. Number of individuals selected from each collection.

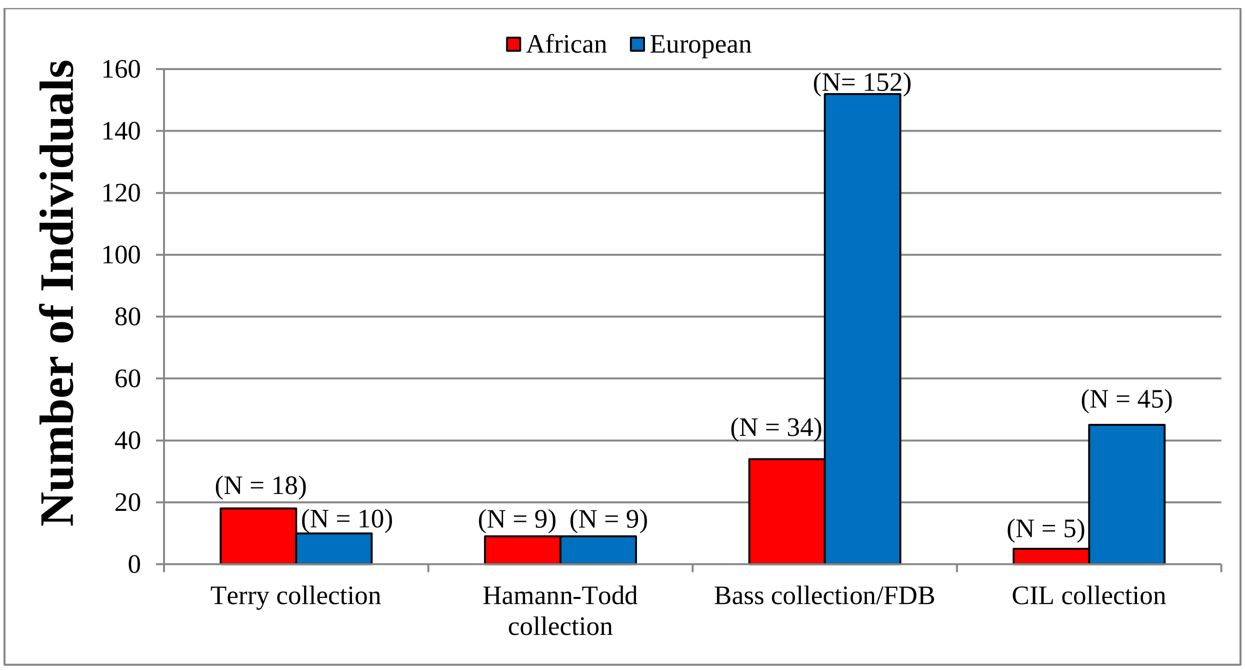

Figure 4. Ancestral composition of American collections.

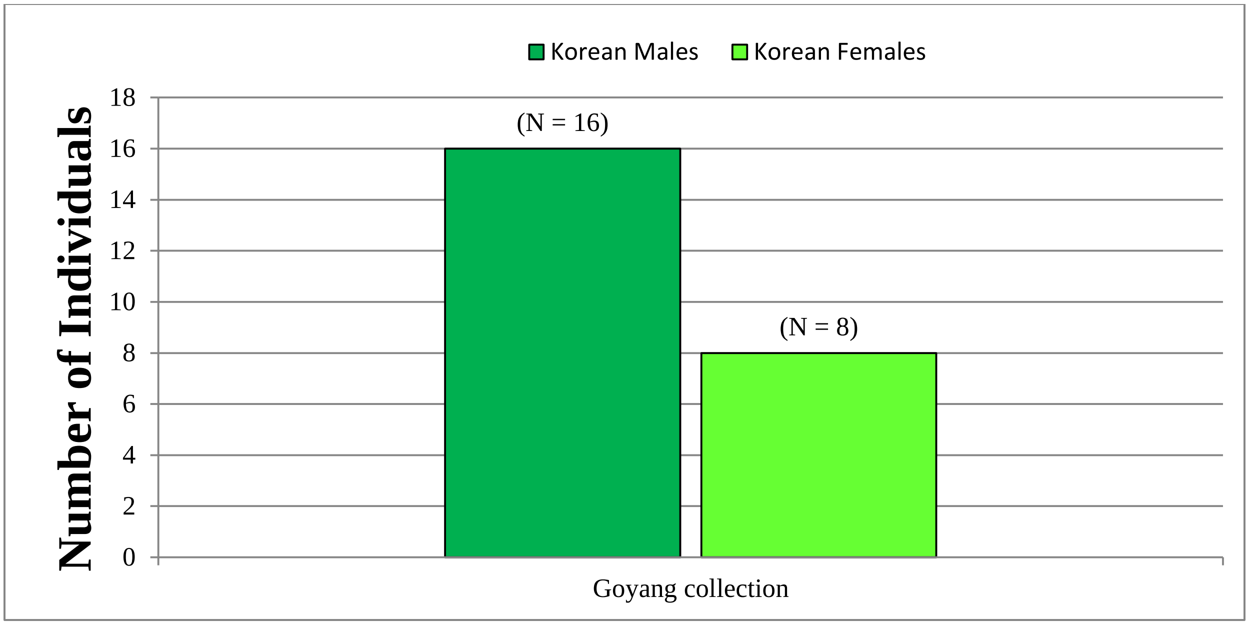

Figure 5. Sex distribution of Korean individuals sampled from the Goyang collection.

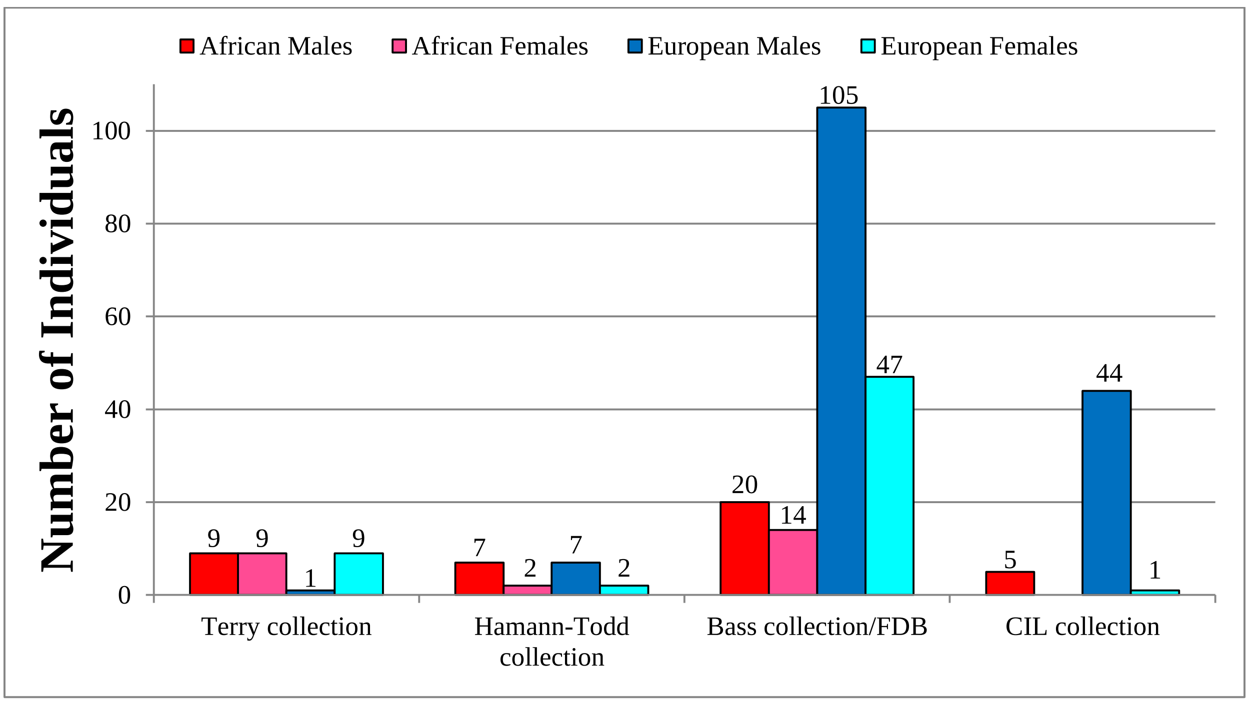

Figure 6. Sex distribution of African and European ancestry of the American collections.

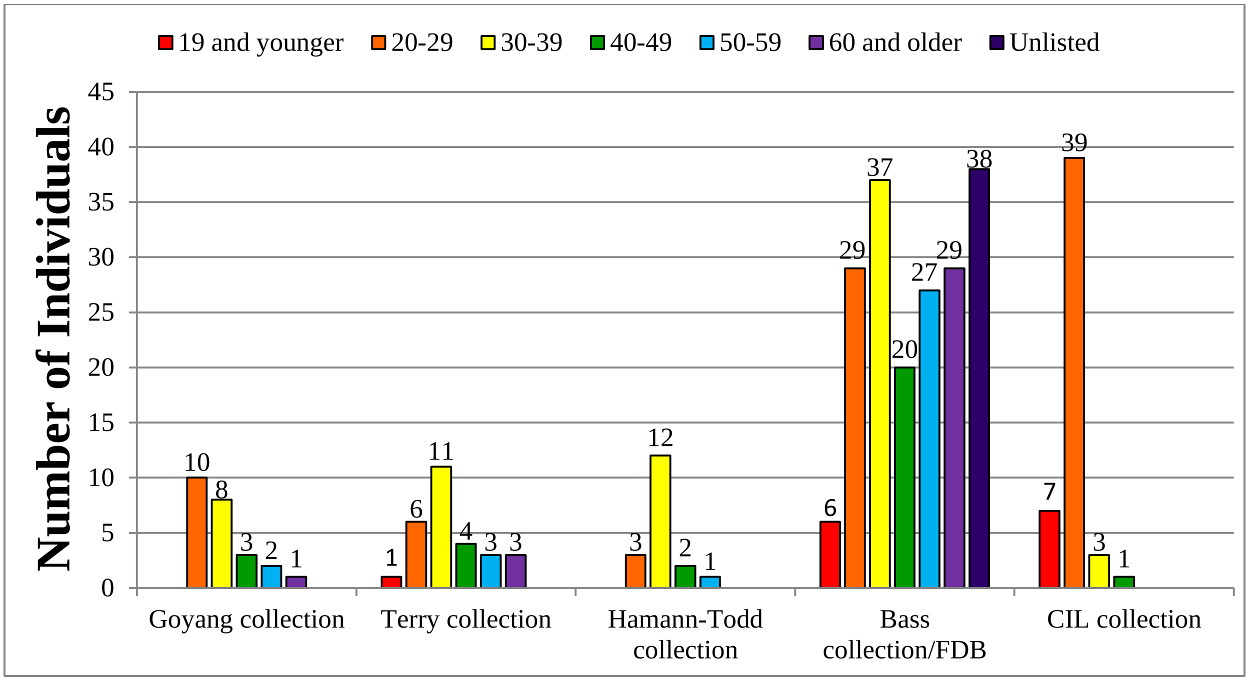

Figure 7. Age distribution of each skeletal collection.

From 1920 to 1965, Robert J. Terry amassed a skeletal collection of cadavers obtained from St. Louis hospitals and morgues (Hunt and Albanese, 2005). Currently the collection contains about 1,728 skeletons of European or African ancestry of lower socioeconomic class from all across Missouri (Hunt and Albanese, 2005). As the collection was created when the use of racial classification was prevalent, the individuals of African and European ancestry are still referred to as being Black or White based on the soft tissue morphology examined at time of death (Wedel, 2007). Individuals included in this study were males and females between 17 years old and 75 years old at the time of death. While the individuals comprising the Terry collection died between 1920 and 1965, some were born as early as the 1840s, which creates a small overlap with the lifetimes of individuals in the Goyang collection (İşcan, 1990). Upon Terry's death, the collection was relocated to the Smithsonian Institution where it remains to this day (İşcan, 1990). Metric data from 28 individuals from the Terry collection was selected; of these, 18 are of African ancestry and 10 of European.

Located in Cleveland, Ohio, the Hamann-Todd collection houses the remains of around 3,100 individuals who died between 1925 and 1940 (St. Hoyme and İşcan, 1989). Like the Terry collection, all individuals are of either European or African ancestry and during life were of lower socioeconomic status similar to those found in the Terry collection (İşcan, 1990). Most had migrated from Europe or the Southern United States in an effort to find better job opportunities in the industrialized North, whereas, the geographic pasts of most of the individuals from the Terry collection are not well-known (İşcan, 1990). Osteometric data from 18 individuals from this collection, 9 of African ancestry and 9 of European ancestry, are included in this thesis.

The William M. Bass Donated Skeletal Collection was started in 1981 at the University of Tennessee and today contains around 900 individuals from over 36 states (WM Bass Donated Skeletal Collection, 2011). All individuals were donated to the collection and have extensive documentation on their biological profile as well as the exact cause of death and medical history (WM Bass Donated Skeletal Collection, 2011). The majority of the sample population of European ancestry was born after 1940 and was of middle to upper socioeconomic standing (WM Bass Donated Skeletal Collection, 2011). The Forensic Anthropology Data Bank (FDB), also located at the University of Tennessee, was established with funding from the National Institute of Justice in 1986 (Forensic Anthropology Data Bank, 2011). It is composed of submitted skeletal and demographic data from over 1,800 forensic cases from across the country and other modern skeletal remains found in various collections (Forensic Anthropology Data

Bank, 2011). The combined data is used for research, like all the other collections, as well as the reference data population for FORDISC 3.0, a statistical tool that can be utilized to predict ancestry and stature based on craniometric measurements and standard osteometric measurements (WM Bass Donated Skeletal Collection, 2011). One hundred and eighty-six individuals, measured by Adams and Byrd, including: 34 of African ancestry and 152 of European ancestry are included in this study.

The CIL collection is composed of osteometric measurements collected from identified military remains at the Joint POW/MIA Accounting Command in Honolulu, Hawaii (Byrd and Adams, 2003). Because of their military enrollment, information is available on each individual's stature, weight, ancestry, and overall health before the time of their death (Byrd and Adams, 2003). From this collection, 50 individuals were selected for data collection: 5 of African ancestry and 45 of European ancestry.

When all the datasets from the various collections are combined, a total of 306 individuals were selected for data collection and analysis. The Korean sample population contains a total of 24 individuals from the Goyang collection while the American sample of 282 individuals, 66 of African ancestry and 216 of European ancestry, was pooled from the Terry collection, Hamann-Todd collection, Bass collection, and the CIL collection.

Methods

A total of 104 different measurements were collected for this study, all standard osteometric measurements utilized by most anthropologists (Buikstra and Ubelaker, 1994) and 65 osteometric sorting measurements developed for fragmentary analysis (Byrd and Adams, 2003). Anthropologists examine a diverse number of cases in various degrees of completeness and fragmentation. With fragmentary remains, it is difficult or impossible to collect meaningful standard measurements as most are defined such that the entire bone must be available to be taken correctly, and so having the ability to collect data from the fragments that are present helps the identification process considerably (Byrd and Adams, 2003). Each standard osteometric measurement is numbered, and so the newer supplemental osteometric sorting measurements were numbered in the same manner so as to follow the order during data collection and clustered by letter to distinguish them from standard measurements while preserving the established number scheme (Byrd and Adams, 2003). Definitions explaining the manner in which significant measurements were taken can be found in Appendix A.

Of the osteometric sorting measurements used in this study, 19 were taken on bones composing the upper limbs, 13 from the carpals and metacarpals, 6 from the sacrum and innominates, 13 from the bones of the lower limbs, and 14 on the tarsals and metatarsals. A detailed list of all osteometric measurements, the bones upon which they were utilized, and their descriptions can be found in Table 1. Measurements are in millimeters and were taken using digital calipers, spreading calipers, or an osteometric board. All digital caliper measurements were taken to the nearest hundredth millimeter. Appendix B lists all data collected from the 24 Koreans by skeletal region and osteometric sorting measurements.

Table 1. Osteometric sorting measurements.

Measurement	Description
Clavicle	
37A	Maximum Width at the Distal End
37B	Breadth at the Inflexion Point at the Distal End*
37C	Maximum Thickness at the Inflexion Point at the Distal End
37D	Maximum Width at the Proximal End*
Scapula	
39A	Maximum Length of the Glenoid Fossa*
39B	Maximum Width of the Glenoid Fossa
39D	Minimum Length from Scapular Notch to Axillary Border
Humerus	
41A	Total Breadth of the Capitulum-Trochlea*
42A	Anterior-Posterior Breadth of the Head*
44B	Minimum Diameter of the Diaphysis*
44D	Maximum Diameter of Diaphysis at the Deltoid Tuberosity
Radius	
47A	Maximum Diameter of the Radial Tuberosity
47B	Maximum Diameter of the Diaphysis Distal to the Radial Tuberosity*
47C	Minimum Diameter of the Diaphysis Distal to the Radial Tuberosity*
47D	Maximum Diameter of the Head*
47E	Breadth of the Distal Epiphysis*
Ulna	
51A	Minimum Diameter of the Diaphysis including the Interosseous Crest*
51B	Minimum Diameter of the Diaphysis*
51C	Breadth of the Semilunar Notch
Hand	
52.5A	Maximum Length of the 1st Metacarpal*
52.5B	Maximum Length of the 2nd Metacarpal*
52.5C	Maximum Length of the 3rd Metacarpal*
52.5D	Maximum Length of the 4th Metacarpal*
52.5E	Maximum Length of the 5th Metacarpal*
52.5F	Maximum Length of the Scaphoid
52.5G	Maximum Length of the Lunate
52.5H	Maximum Length of the Triquetral
52.5I	Maximum Length of the Pisiform
52.5J	Maximum Length of the Trapezium
52.5K	Maximum Length of the Trapezoid
52.5L	Maximum Length of the Capitate
52.5M	Maximum Length of the Hamate

Measurement	Description
Sacrum	
55J	Maximum Breadth with the Osteometric Board*
Innominate	
59A	Thickness of the Ilium at the Sciatic Notch
59B	Maximum Breadth of the Ischium
59C	Minimum Breadth of the Pubis
59D	Minimum Breadth of the Ilium from the Sciatic Notch*
59E	Maximum Diameter of the Acetabulum*
Femur	
68A	Minimum Anterior-Posterior Diameter of the Diaphysis*
68B	Minimum Medial-Lateral Diameter of the Diaphysis
68D	Minimum Superior-Inferior Neck Diameter*
68E	Maximum Diameter along the Linea Aspera
Tibia	
74A	Maximum Anterior-Posterior Diameter Distal to the Popliteal Line*
74B	Minimum Anterior-Posterior Diameter
74F	Maximum Anterior-Posterior Distance of the Distal Articular Surface*
Patella	
74.5A	Maximum Length
74.5B	Maximum Breadth*
74.5C	Maximum Thickness
Fibula	
76A	Maximum Diameter of the Diaphysis*
76B	Minimum Diameter of the Diaphysis
76C	Maximum Breadth at the Distal End*
Calcaneus	
78A	Minimum Breadth (Height) Distal to Articular Facets*
78B	Posterior Length*
Talus	
79	Minimum Trochlear Breadth
79A	Maximum Length *
Foot	
80A	Maximum Length of the 1st Metatarsal
80B	Maximum Length of the 2nd Metatarsal*
80C	Maximum Length of the 3rd Metatarsal*
80D	Maximum Length of the 4th Metatarsal*
80E	Maximum Length of the 5th Metatarsal*
80F	Maximum Length of the Cuboid*
80G	Maximum Length of the Navicular*

Measurement	Description
80H	Maximum Length of the 1st Cuneiform*
80I	Maximum Length of the 2nd Cuneiform
80J	Maximum Length of the 3rd Cuneiform*

*Osteometric sorting measurement found to be significant through ANOVA testing.

While individuals were selected for data collection based on their relative completion, not all osteometric sorting measurements could be collected from every individual nor could they always be collected on both sides of the skeleton. Since this study is not focusing on handedness or other siding differences in bones, a final single measurement was created by averaging the left and right measurements, if available, or by using the single measurement from either side. Once measurements were finalized, the variables chosen for analysis were restricted to osteometric sorting measurements in an effort to decrease the number of measurements taken when compared to the population sample sizes.

Two statistical methods were performed using SPSS 20.0 to determine the postcranial measurements of significance when assessing ancestry. Skeletal remains are not always complete, and so the fewer measurements that are needed to predict ancestry, the more useful the assessment. Since there are three main ancestral groups that needed to compare against each other, ANOVA tests were carried out on all osteometric sorting measurements instead of independent sample t-tests. ANOVA tests are appropriate analyses for assessing variation as they evaluate the differences between groups and compare them to the amount of variation that can be contributed to error (Wescott, 2005). When the group means are significantly different than one another, the variation between groups is found to be larger than the variation that could be contributed to measurement error (Wescott, 2005). Further analyses are limited to measurements determined to be significant as the goal of this study is to obtain high classification accuracy while utilizing a minimal number of variables so as to better assist in identification of fragmentary remains and to prevent analyses from being made with more variables than individuals within the sample populations.

The postcranial elements were divided into areas of the body to create a series of discriminant function analyses; these included a combination of: upper limb measurements, hand measurements, pelvic measurements, lower limb measurements, and foot measurements. This was done as not all postcranial remains are complete, and by having functions that are tailored to specific regions as well as to a combination of several regions, the method could be applicable to incomplete skeletal remains and complete skeletal remains. As such, the combination of several skeletal regions will create a measurements overlap between analyses of a single region and of multiple regions. Discriminant function analysis elucidates best group membership, making it easier to classify individuals of a particular ancestry by maximizing the differences between groups and minimizing the variation within groups (Spradley et al., 2008). There are several forms of discriminant analysis that can be utilized for classification. This study used forward stepwise analysis as an additional effort to maximize best classification predictions while minimizing the number of measurements needed.

Stepwise analysis begins with a single first “step” which occurs when the variable with the greatest discriminating power is chosen from all other variables put forth for analysis (İşcan and Cotton, 1990). This process is repeated as successive steps in which the next measurement variable that has the best capability of maximizing the differences between groups is added to the variable or variables already selected for analysis (İşcan and Cotton, 1990). This selection process and addition of variables for analysis ends once the function’s discriminatory power no longer improves significantly (İşcan and Cotton, 1990). The final function for ancestry prediction will contain all the variables chosen through the stepwise analysis in combination with coefficients and a constant and a cutoff point that denotes a clear group boundary in which one side is highly likely to be one ancestral group and the other side a different ancestral group. Leave-one-out classification, also known as cross-validation, was performed with all discriminant analyses to test how successful the derived function was in the correct classification of different groups. In this way, it helped reduce the amount of bias by omitting the case being classified from the sample set (Wescott, 2006).

The discriminant analyses were separated into two parts: Korean and African/European and European and African. Initial analyses were performed upon the three ancestral populations with the hopes of creating functions that could classify all three groups relatively well. Initial analyses, however, revealed that Africans often misclassified as European while the Korean and European populations classified well. This created inflated classification rates overall but did not discriminate equally as well with each ancestral population. The higher misclassification of African ancestry was likely due to the higher level of genetic heterogeneity in the African American sample populations than in those from continental Africa (Duray et al., 1999). American individuals of African ancestry are likely to have a combination of West African and European ancestry with a smaller part of the African American population having Native American ancestry (Duray et al., 1999). This shared genetic background can lead to increased similarities in postcranial morphological features between the African and European ancestry samples, thus increasing the likelihood that African American individuals will misclassify as European.

It was then decided that the Europeans and Africans should be pooled together for analysis to get a more honest classification of ancestry from significant variables when comparing Koreans. This approach is supported in previous studies of the femur (Gilbert and Gill, 1990; Wescott, 2005; Wescott, 2006; Wescott and Srikanta, 2008). Separate discriminate analyses were then run on the European and African sample populations examining the same combination of skeletal regions for the best functions that predict ancestry for both.

CHAPTER FOUR: RESULTS

ANOVA Test Results

A total of 38 of the original 65 osteometric sorting measurements were determined by ANOVA tests to be significant. Each measurement determined to be significant can be found in Table 2 along with the measurement means, their standard deviations, and the measurement's p-value by each ancestral group. Most of the differences between groups can be attributed to size with both Africans and Europeans being larger than Koreans in every measurement. This can easily be seen in larger minimum diaphyseal measurements of long bones, especially in the femur, and longer maximum lengths of metacarpals and metatarsals. While many of the African and European measurements are similar in size, the averages of the maximum breadth of the sacrum, minimum breadth of the ilium at the sciatic notch, and maximum diameter of the acetabulum are consistently larger in Europeans. However, the mean maximum length of both the metacarpals and metatarsals are slightly longer in African individuals, and the minimum diaphyseal diameters of most of the long bones are somewhat larger.

Table 2. Significant osteometric sorting measurements and their standard deviations (mm).

Measurement	**Korean**	**African**	**European**	**p-value**
Clavicle				
Breadth at the Inflexion Point at the Distal End (37B)	16.96 ± 1.82	18.34 ± 3.50	19.01 ± 3.00	0.015
Maximum Width at the Proximal End (37D)	19.78 ± 2.73	26.17 ± 3.11	25.93 ± 3.50	0.000
Scapula				
Maximum Length of the Glenoid Fossa (39A)	33.40 ± 2.35	36.57 ± 4.19	36. 63 ± 3.96	0.004
Humerus				
Total Breadth of the Capitulum-Trochlea (41A)	40.98 ± 2.97	44.60 ± 5.50	44.70 ± 4.27	0.003
Anterior-Posterior Breadth of the Head (42A)	38.41 ± 2.24	43.36 ± 5.15	43.31 ± 4.03	0.000
Minimum Diameter of the Diaphysis (44B)	16.38 ± 1.88	18.63 ± 2.62	17.72 ± 2.51	0.002
Radius				
Maximum Diameter of the Diaphysis Distal to the Radial Tuberosity (47B)	16.04 ± 1.64	18.24 ± 3.11	17.69 ± 2.81	0.009

Measurement	Korean	African	European	p-value
Minimum Diameter of the Diaphysis Distal to the Radial Tuberosity (47C)	10.44 ± 0.99	11.55 ± 1.48	10.94 ± 1.29	0.004
Maximum Diameter of the Head (47D)	21.19 ± 2.07	23.97 ± 3.08	23.35 ± 2.48	0.007
Breadth of the Distal Epiphysis (47E)	30.83 ± 2.55	33.46 ± 4.11	33.48 ± 3.71	0.016
Ulna				
Minimum Diameter of the Diaphysis including the Interosseous Crest (51A)	10.65 ± 1.06	11.61 ± 1.82	10.93 ± 1.42	0.029
Minimum Diameter of the Diaphysis (51B)	9.43 ± 0.74	10.21 ± 1.30	9.99 ± 1.22	0.049
Hand				
Maximum Length of the 1st Metacarpal (52.5A)	43.29 ± 2.99	48.33 ± 4.62	46.83 ± 4.17	0.000
Maximum Length of the 2nd Metacarpal (52.5B)	63.42 ± 3.45	72.10 ± 7.05	70.30 ± 5.64	0.000
Maximum Length of the 3rd Metacarpal (52.5C)	62.28 ± 3.66	71.60 ± 7.31	68.68 ± 5.99	0.000
Maximum Length of the 4th Metacarpal (52.5D)	53.89 ± 3.33	61.47 ±6.42	58.53 ± 4.97	0.000
Maximum Length of the 5th Metacarpal (52.5E)	49.69 ± 2.91	57.03 ± 5.50	54.51 ± 5.16	0.000
Sacrum				
Maximum Breadth with the Osteometric Board (55J)	109.57 ± 4.26	110.90 ± 9.49	118.92 ± 6.67	0.000
Innominate				
Minimum Breadth of the Ilium from the Sciatic Notch (59D)	59.77 ± 4.48	61.58 ± 6.37	64.16 ± 6.06	0.004
Maximum Diameter of the Acetabulum (59E)	54.08 ± 3.25	55.28 ± 5.96	57.07 ± 5.05	0.029
Femur				
Minimum Anterior-Posterior Diameter of the Diaphysis (68A)	23.50 ± 2.55	27.65 ± 3.43	27.36 ± 3.05	0.000
Minimum Superior-Inferior Neck Diameter (68D)	28.89 ± 2.72	32.37 ± 4.45	33.51 ± 3.90	0.000
Tibia				
Maximum Anterior-Posterior Diameter Distal to the Popliteal Line (74A)	29.22 ± 3.21	33.46 ± 4.01	33.36 ± 4.66	0.000
Maximum Anterior-Posterior Distance of the Distal Articular Surface (74F)	28.25 ± 2.44	30.61 ± 4.06	31.84 ± 4.24	0.002
Patella				
Maximum Breadth (74.5B)	40.50 ± 7.36	43.29 ± 5.02	44.10 ± 4.22	0.041
Fibula				
Maximum Diameter of the Diaphysis (76A)	14.70 ± 2.19	15.95 ± 2.26	16.32 ± 2.30	0.015
Maximum Breadth at the Distal End (76C)	23.87 ± 2.15	26.31 ± 4.46	26.50 ± 2.52	0.003
Calcaneus				
Minimum Breadth (Height) Distal to Articular Facets (78A)	35.24 ± 3.06	37.35 ± 4.53	39.07 ± 3.92	0.001
Posterior Length (78B)	51.74 ± 3.39	59.30 ± 5.95	59.68 ± 5.11	0.000

Measurement	Korean	African	European	p-value
Talus				
Maximum Length (79A)	54.58 ± 3.75	60.22 ± 6.36	61.47 ± 5.65	0.000
Foot				
Maximum Length of the 2nd Metatarsal (80B)	69.30 ± 4.62	80.20 ± 7.87	77.92 ± 6.94	0.000
Maximum Length of the 3rd Metatarsal (80C)	64.92 ± 4.74	75.74 ± 7.77	73.42 ± 6.13	0.000
Maximum Length of the 4th Metatarsal (80D)	64.96 ± 3.74	73.62 ± 7.76	71.54 ± 6.12	0.001
Maximum Length of the 5th Metatarsal (80E)	65.73 ± 5.41	74.53 ± 7.56	73.31 ± 6.65	0.001
Maximum Length of the Cuboid (80F)	37.13 ± 2.59	41.43 ± 4.32	40.00 ± 3.52	0.001
Maximum Length of the Navicular (80G)	38.68 ± 3.36	42.60 ± 4.84	41.31 ± 4.01	0.029
Maximum Length of the 1st Cuneiform (80H)	37.89 ± 2.90	41.47 ± 4.12	41.27 ± 3.99	0.010
Maximum Length of the 3rd Cuneiform (80J)	27.31 ± 1.56	30.56 ± 3.67	29.70 ± 2.55	0.020

Korean Ancestry and African/European Ancestry – Discriminant Function Analysis

Once the measurements with significant population differences were denoted by ANOVA tests, a series of stepwise discriminant function analyses were carried out to determine the most useful measurements to differentiate Korean individuals from those of European or African ancestry. For an individual to be included in the stepwise technique, all of the variables being considered must be present. If a single measurement was missing, the individual in question was excluded. As a result, the total number of individuals representing Korean ancestry and African/European ancestry in each function fluctuated based on the relative completeness of each individual measured and the region(s) under examination as not all individuals lacked the same measurements and functions were created using bones in different parts of the postcranial skeleton. All functions had smaller sample sizes than the original totals (24 Korean, 66 African, and 216 European) collected from the five skeletal collections and Forensic Anthropology Data Bank for each ancestry.

Fifteen discriminant functions were synthesized from the measurements determined to be significant in each ancestral analysis. The two functions with the best cross-validated classification percentages for Koreans and Africans/Europeans are outlined in detail below. The other 13 functions were created in the same manner but have been condensed into a summary table (Table 8, which is depicted later in this chapter after *Discriminant Function One* and *Discriminant Function Two*) containing the region to which the function corresponds, its cutoff point, and the ancestral classification of discriminant scores above or below the cutoff point.

Discriminant Function One

The discriminant function with the highest classification percentage for Korean ancestry and African/European ancestry was from measurements of the shoulder girdle and upper limbs. The stepwise analysis was made up of two steps, with the first step having a significance of $p = 0.001$ and the second step having a significance of $p = 0.000$. Step one of the function found the maximum width of the proximal end of the clavicle (37D) to be the most significant of the 12 measurements chosen for analysis. The minimum diameter of the ulnar diaphysis including the interosseous crest (51A) was included in the second step and completed the analysis.

The end function has a low eigenvalue of 0.210, a high Wilks' lambda of 0.826, and a canonical correlation of 0.417. While these values are not ideal, the discriminant function produced does classify both groups with at least 80% accuracy. While all the upper limb and shoulder girdle measurements were found to be larger in Africans and Europeans, the minimum diameter of the ulnar diaphysis (51A) was the only measurement in the discriminant structure matrix that was found to be greater in Koreans, though slight. This does not mean that the measurement itself was large in Korean individuals, but the fact that all the other measurements in the structure matrix showed African/Europeans being proportionally larger with the exception of 51A suggests that this measurement might be proportionally larger in the Korean individuals analyzed. The maximum width at the proximal end of the clavicle (37D) was found to have the greatest size difference of all upper limb and shoulder girdle measurements and was significantly larger in Africans and Europeans. Table 3 contains a summary of each variable's unstandardized coefficient as well as the function's constant.

Table 3. Unstandardized coefficients of Function One predicting African/European from Korean ancestry.

Measurement	Unstandardized Discriminant Function Coefficients
37D (X_1)	0.357
51A (X_2)	-0.368
Constant	-5.244

The discriminant function created by these two significant measurements in stepwise analysis will be referred to as Function One and is the following:

$$\text{Discriminant score (D)} = 0.357(X_1) - 0.368(X_2) - 5.244$$

If the calculated discriminant score is greater than the function cutoff point of -0.955, the mean of Korean and African/European scores, then the individual is likely to have African or European ancestry. If the discriminant score is less than the cutoff point of -0.955, then the individual is likely to have Korean ancestry. Fifteen of the 24 Korean individuals had both the clavicle and ulna measurement, making them eligible for analysis, and of these, 93.3% were correctly classified and cross-validated based on Function One listed above. Cross-validation was completed by classifying each individual according to the function derived without having the tested measurements as part of the reference population. This was done for each individual found to be complete enough for analysis. Ninety-four African/European individuals were eligible for analysis based on complete measurements, and when their discriminant scores were calculated using Function One, 80.9% were correctly classified and cross-validated as having

African/European ancestry. The probabilities of ancestral group membership can be found in Table 4.

Table 4. Probabilities of ancestral group membership based on upper limb measurements.

			Predicted Group Membership		
		Ancestry	Korean	African/European	**Total**
Original	Count	Korean	14	1	15
		African/European	18	76	94
	%	Korean	93.3	6.7	100.0
		African/European	19.1	80.9	100.0
Cross-validated	Count	Korean	14	1	15
		African/European	18	76	94
	%	Korean	93.3	6.7	100.0
		African/European	19.1	80.9	100.0

82.6% of original grouped cases correctly classified.
Cross-validation is done only for those cases in the analysis. In cross-validation, each case is classified by the functions derived from all cases other than that case.
82.6% of cross-validated grouped cases correctly classified.

Discriminant Function Two

The discriminant function with the second highest classification percentages for differentiating Korean ancestry from African/European ancestry included measurements from the shoulder girdle, upper limbs, and hand. The stepwise analysis was made up of three steps, with the first step and second step having a significance of p = 0.001 and the third step having a significance of p = 0.000. Steps one and two of the function found the maximum width of the proximal end of the clavicle (37D) and the minimum diameter of the ulnar diaphysis (51A) to be significant as was previously determined in Function One. The third step found the maximum length of the 4^{th} metacarpal (52.5D) to be a significant measurement in the hand, which completed this analysis.

The end function has a slightly higher eigenvalue of 0.295, a lower Wilks' lambda of 0.772, and a canonical correlation of 0.477. While these values are still not ideal, the discriminant function produced does classify both groups with almost 82% accuracy. Again, the minimum diameter of the ulnar diaphysis (51A) was the only measurement in the discriminant structure matrix that was found to be greater in Koreans, though only slightly, while both the maximum width of the proximal end of the clavicle (37D) and maximum length of the 4th metacarpal (52.5D) were found to be quite larger in Africans and Europeans. This does not mean that the ulnar measurement itself was larger in Korean individuals, but it does suggest that this measurement might be proportionally larger in individuals from the Goyang collection. Table 5 contains a summary of each variable's unstandardized coefficient as well as the function's constant.

Table 5. Unstandardized coefficients of Function Two predicting African/European ancestry from Korean ancestry.

Measurement	Unstandardized Discriminant Function Coefficients
37D (X_1)	0.274
51A (X_2)	-0.545
52.5D (X_3)	0.112
Constant	-7.788

The discriminant function created by these three significant measurements in stepwise analysis will be referred to as Function Two and is the following:

$$\text{Discriminant score (D)} = 0.274(X_1) - 0.545(X_2) + 0.112(X_3) - 7.788$$

If the calculated discriminant score is greater than the function cutoff point of -1.057, then the individual is likely to have African or European ancestry, while a discriminant score of less than the cutoff point suggests that the individual is likely to have Korean ancestry. Thirteen of the 24 Korean individuals were eligible for analysis based on the three measurements composing the discriminant function. All Koreans were correctly classified in the initial analysis, but this percentage dropped to 84.6% after cross-validation. Eighty-eight Africans/Europeans had complete measurements and 83.0% were correctly classified initially. Upon cross-validation of Function Two, 81.8% of Africans and Europeans still classified correctly. The probabilities of ancestral group membership based on Function Two can be found in Table 6.

Table 6. Probabilities of ancestral group membership from upper limb and hand measurements.

			Predicted Group Membership		
		Ancestry	Korean	African/European	**Total**
Original	Count	Korean	13	0	13
		African/European	15	73	88
	%	Korean	100.0	0.0	100.0
		African/European	17.0	83.0	100.0
Cross-validated	Count	Korean	11	2	13
		African/European	16	72	88
	%	Korean	84.6	15.4	100.0
		African/European	18.2	81.8	100.0

85.2% of original grouped cases correctly classified.
Cross-validation is done only for those cases in the analysis. In cross-validation, each case is classified by the functions derived from all cases other than that case.
82.2% of cross-validated grouped cases correctly classified.

Thirteen other discriminant functions were created for the classification of Koreans and Africans/Europeans. The resulting correct classification percentages and cross-validation percentages can be found in Table 7 along with the skeletal region that was scrutinized and the sample sizes of each ancestral group. The lowest Korean correct classification percentages were found in functions that examined only the pelvis or the lower limbs and feet. All other discriminant functions resulted in correct classifications of 78.3% or greater. The pelvis and the combination of lower limbs with foot measurements remained among the lowest classification percentages when cross-validated at 71.4% and 68.8% respectively; however, a noticeable decrease in classification percentages was present in the classification of upper limb and lower limb in combination, hand and foot in combination, and the pelvis with lower limb measurements. Even after cross-validation, Koreans tended to classify better than Africans/Europeans in all functions except four: those that combined upper and lower limb measurements, hand and foot measurements, pelvis and lower limb measurements, and lower limb with foot measurements.

The lowest correct classification of African/Europeans in this study was in the discriminant function of the upper limbs in combination with the pelvis at 66.7%. Nine of the 15 discriminant functions have classification rates of 77% or greater with the remaining 6 ranging from 66.7% to 72.2%. The highest classification percentage for Africans/Europeans was found in the function analyzing measurements of the upper and lower limbs together at 90.3%, when originally classified, and 89.2% upon cross-validation. The percentages of all other discriminant functions remained the same or similar to their original classification percentages upon cross-validation.

Table 7. Results of all Korean and African/European discriminant analysis.

Skeletal Region	Korean	African/ European	Correct Classification % (Korean)	Correct Classification % (African/ European)	Cross-Validation % (Korean)	Cross-Validation % (African/ European)
Upper Limb	15	94	93.3	80.9	93.3	80.9
Hand	19	97	89.5	72.2	89.5	72.2
Pelvis	14	81	71.4	67.9	71.4	67.9
Lower Limb	23	108	82.6	71.3	82.6	71.3
Foot	15	94	86.7	71.3	86.7	71.3
Upper Limb, Hand	13	88	100.0	83.0	84.6	81.8
Upper Limb, Lower Limb	14	93	85.7	90.3	71.4	89.2
Upper Limb, Pelvis	16	96	93.8	66.7	87.5	66.7
Upper Limb, Pelvis, Femur	16	96	87.5	77.1	87.5	77.1
Upper Limb, Pelvis, Lower Limb	16	96	87.5	77.1	87.5	77.1
Hand, Foot	17	81	82.4	85.2	64.7	82.7
Pelvis, Femur	23	98	82.6	83.7	82.6	79.6
Pelvis, Lower Limb	23	94	78.3	85.1	73.9	81.9
Pelvis, Lower Limb, Foot	15	94	86.7	71.3	80.0	71.3
Lower Limb, Foot	16	87	75.0	78.2	68.8	78.2

Table 8 summarizes each discriminant function that was developed with the stepwise method to limit the variables of equations to those most significant and to determine the most useful measurements of each postcranial skeletal region. The measurements alone for each function are listed in Table 9 while Figure 8 depicts their frequency of use in analyses. When a skeletal region or regions was being analyzed, all measurements for that region(s) that were found to be significant using ANOVA tests were entered for discriminant analysis and given equal opportunity to be chosen by stepwise analysis. The measurements in Table 9 were the measurements deemed to be the most significant from all the available measurements. By far, the minimum width at the proximal end of the clavicle (37D) is the most frequently included measurement for ancestral determination between Koreans and Africans/Europeans. The second most frequently included measurement is the minimum anterior-posterior diameter of the femoral diaphysis (68A). The remaining measurements come from the ulna, metacarpals (1st, 2nd, and 4th), sacrum, innominate, femur, fibula, calcaneus, and 2nd metatarsal.

Table 8. Summary of all discriminant functions to differentiate between Koreans and Africans/Europeans for each skeletal region.

Discriminant Functions of Each Skeletal Region		
	Upper Limb	
	Discriminant score (D) = 0.357(37D) - 0.368(51A) - 5.244	
Cutoff: -0.955	Above: African/European	Below: Korean
	Hand	
	Discriminant score (D) = 0.165(52.5B) - 11.468	
Cutoff: -0.3735	Above: African/European	Below: Korean
	Pelvis	
	Discriminant score (D) = 0.121(55J) - 13.916	
Cutoff: -0.271	Above: African/European	Below: Korean
	Lower Limb	
	Discriminant score (D) = 0.318(68A) - 8.507	
Cutoff: -0.422	Above: African/European	Below: Korean
	Foot	
	Discriminant score (D) = 0.136(80B) - 10.644	
Cutoff: -0.4815	Above: African/European	Below: Korean
	Upper Limb, Hand	
	Discriminant score (D) = 0.274(37D) - 0.545(51A) + 0.112(52.5D) - 7.788	
Cutoff: -1.057	Above: African/European	Below: Korean
	Upper Limb, Lower Limb	
	Discriminant score (D) = 0.220(37D) - 0.385(51A) + 0.337(68A) - 0.331(76A) - 5.351	
Cutoff: -1.2055	Above: African/European	Below: Korean
	Upper Limb, Pelvis	
	Discriminant score (D) = 0.307(37D) - 8.042	
Cutoff: -0.641	Above: African/European	Below: Korean
	Upper Limb, Pelvis, Femur	
	Discriminant score (D) = 0.308(37D) - 8.038	
Cutoff: -0.7785	Above: African/European	Below: Korean
	Upper Limb, Pelvis, Lower Limb	
	Discriminant score (D) = 0.300(37D) - 7.810	
Cutoff: -0.7405	Above: African/European	Below: Korean

Discriminant Functions of Each Skeletal Region		
	Hand, Foot	
Discriminant score (D) = -0.517(52.5A) + 0.265(52.5D) + 0.228(78B) - 4.772		
Cutoff: -0.708	Above: African/European	Below: Korean
	Pelvis, Femur	
Discriminant score (D) = -0.390(59E) + 0.245(68A) + 0.379(68D) - 1.615		
Cutoff: -0.6715	Above: African/European	Below: Korean
	Pelvis, Lower Limb	
Discriminant score (D) = -0.312(59E) + 0.348(68A) + 0.390(68D) - 0.253(76A) - 0.630		
Cutoff: -0.814	Above: African/European	Below: Korean
	Pelvis, Lower limb, Foot	
Discriminant score (D) = 0.131(80B) - 10.285		
Cutoff: -0.506	Above: African/European	Below: Korean
	Lower Limb, Foot	
Discriminant score (D) = -0.218(74.5B) + 0.273(78B) - 6.451		
Cutoff: -0.605	Above: African/European	Below: Korean

Table 9. Significant measurements of Koreans and Africans/Europeans as determined by forward stepwise analysis.

Skeletal Region	Measurements in Final Equation
Upper Limb	37D, 51A
Hand	52.5B
Pelvis	55J
Lower Limb	68A
Foot	80B
Upper Limb, Hand	37D, 51A, 52.5D
Upper Limb, Lower Limb	37D, 51A, 68A, 76A
Upper Limb, Pelvis	37D
Upper Limb, Pelvis, Femur	37D
Upper Limb, Pelvis, Lower Limb	37D
Hand, Foot	52.5A, 52.5D, 78B
Pelvis, Femur	59E, 68A, 68D
Pelvis, Lower Limb	59E, 68A, 68D, 76A
Pelvis, Lower Limb, Foot	80B
Lower Limb, Foot	74.5B, 78B

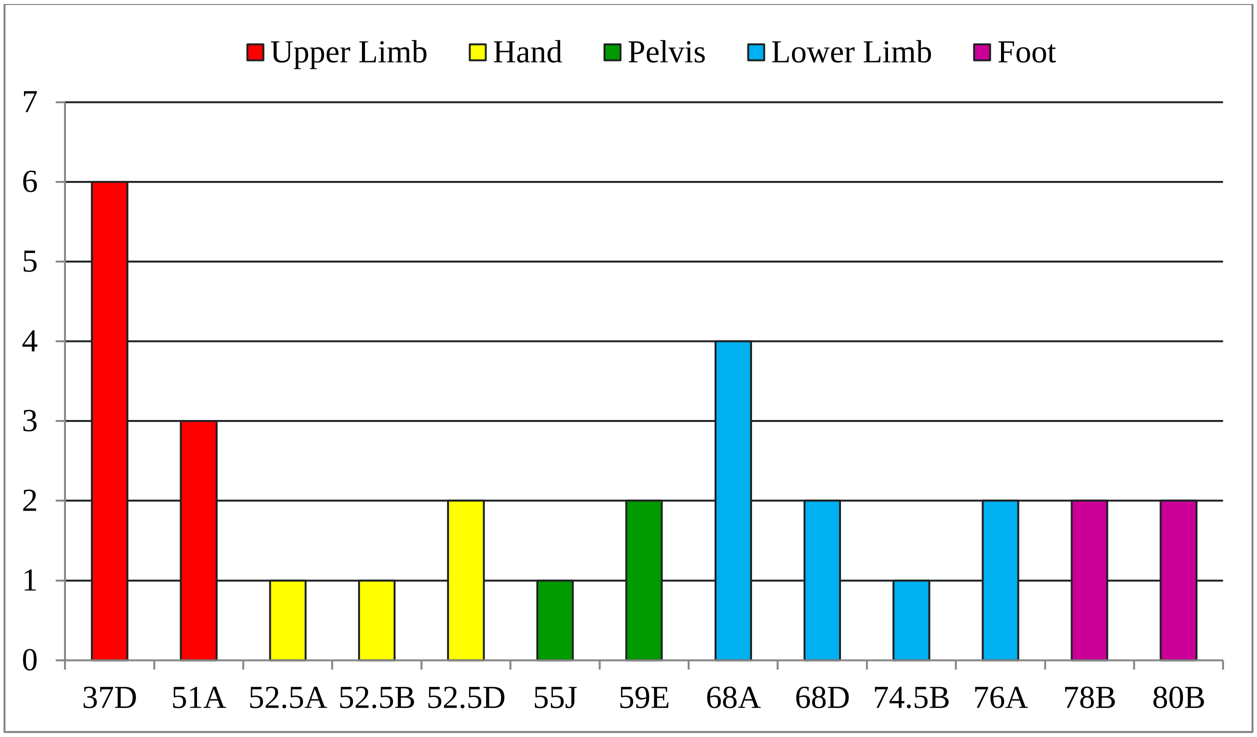

Figure 8. Significant measurements and their frequency of use to distinguish Koreans from Africans/Europeans.

<u>African and European – Discriminant Function Analysis</u>

Discriminant function analysis was carried out on the African and European samples to determine if it was possible to differentiate skeletal remains once they had been determined not to be Korean. Like the previous analyses, the stepwise method was utilized to minimize the variables within each function, and separate functions were derived for skeletal regions and combinations of these regions. For an individual to be considered for discriminant function analysis, all measurements included in the function must be present in that individual. As the measurements employed in each function vary and are based upon their significance in a particular skeletal region, the number of individuals classified from each ancestral group showed some change from function to function.

Fifteen discriminant analyses were attempted from the measurements determined to be significant in each ancestral analysis, resulting in 14 discriminant functions as the measurements of the lower limb alone were not found to be significant enough to create a function for this region. The two functions with the best cross-validated classification percentages for Africans and Europeans are outlined in detail below in the same manner as the findings of the Korean and African/European analyses. The remaining 12 functions were created in the same manner as those reported below but have been compressed into a summary table containing the region to which the function corresponds as well as its cutoff point and the ancestral classification of discriminant scores above or below the cutoff point. This was done to avoid repetition as the process to create the functions was the same as the two discussed at length below.

Discriminant Function Three

The discriminant function found to have the highest classification percentage for African and European ancestry included measurements from the pelvis, lower limbs, and feet. The stepwise analysis was made up of three steps, with all steps having a significance of $p = 0.000$. Step one of the function contains the most significant measurement of the lower body, the maximum breadth of the sacrum with the osteometric board (55J). The maximum length of the cuboid (80F) was added to the function in the second step of the analysis, and the maximum anterior-posterior distance of the distal articular surface of the tibia (74F) was added in the third.

The end function had a high eigenvalue of 1.164, a Wilks' lambda of 0.462, and a canonical correlation of 0.733. These values demonstrate a higher discriminatory ability than those of Function One and Function Two, but the statistical significance of the discriminant scores are equal as $p = 0.000$. The structural trends of each measurement analyzed vary, making the generalization of all measurements being larger or smaller in one group impossible. There are some patterns for each ancestral group that show correlation with particular bones. Concerning the measurements included in this discriminant function, it can be said that the maximum breadth of the sacrum (55J) was broader in Europeans than in Africans and that the maximum length of the cuboid (80F) was greater in Africans. The maximum anterior-posterior distance of the distal articular surface of the tibia (74F) was found to be slightly larger in Europeans. Table 10 contains a summary of each variable's unstandardized coefficient and the function's constant.

Table 10. Unstandardized coefficients of Function Three predicting European ancestry from African ancestry.

Measurement	Unstandardized Discriminant Function Coefficients
55J (X_1)	0.119
74F (X_2)	0.228
80F (X_3)	-0.395
Constant	-4.700

The discriminant function created by these three significant measurements for the classification of African ancestry from European ancestry will be referred to as Function Three and is the following:

$$\text{Discriminant score (D)} = 0.119(X_1) + 0.228(X_2) - 0.395(X_3) - 4.700$$

The function has a cutoff point of -0.037. Discriminant scores found to be greater than this value have a greater than 50% probability of belonging to individuals of European ancestry and those found to be below the cutoff point are more likely of African ancestry. A total of 69 individuals, 39 of European ancestry and 30 of African ancestry, were classified using Function Three. 79.5% of Europeans were correctly classified and cross-validated while Africans classified slightly better overall. African individuals originally classified at 83.3%, and when the function was cross-validated, it correctly predicted ancestry in 80% of African cases. The exact probabilities of membership and the count of cases can be found in Table 11.

Table 11. Probabilities of ancestral group membership from pelvis, lower limb, and foot measurements.

			Predicted Group Membership		
		Ancestry	European	African	**Total**
Original	Count	European	31	8	39
		African	5	25	30
	%	European	79.5	20.5	100.0
		African	16.7	83.3	100.0
Cross-validated	Count	European	31	8	39
		African	6	24	30
	%	European	79.5	20.5	100.0
		African	20.0	80.0	100.0

81.2% of original grouped cases correctly classified.
Cross-validation is done only for those cases in the analysis. In cross-validation, each case is classified by the functions derived from all cases other than that case.
79.7% of cross-validated grouped cases correctly classified.

Discriminant Function Four

Measurements of the lower limbs and foot proved to have the second highest classification percentage for African and European ancestry. The discriminant function produced using stepwise analysis was made up of three steps similar to Function Three, with the first step having a significance of p = 0.031 and the additional two steps having a significance of p = 0.000. Step one listed the maximum length of the cuboid (80F) to be the most significant measurement followed in step two by the maximum anterior-posterior diameter of the distal articular surface of the tibia (74F). Both of these measurements also were found to be significant in Function Three and added to the above mentioned function in the same order of significance. The third step ended the analysis with the addition of the minimum breadth (height) of the calcaneus distal to the articular facets (78A).

The end function has an eigenvalue of 0.554, a Wilks' lambda of 0.644, and a canonical correlation of 0.597. These values are not as high as Discriminant Function Three but are all better than the values found in Functions One and Two that differentiate Korean from African/European ancestry. Without the inclusion of the maximum sacral breadth (55J), the classification percentages for Africans have dropped but have risen inversely in Europeans. Each group correctly classifies with at least 75% accuracy. The maximum length of the cuboid (80F) was still found to be larger in African individuals, and the maximum anterior-posterior distance of the distal articular surface of the tibia (74F) was found to be larger in Europeans. The additional measurement specific to what will be referred to as Function Four, the minimum breadth (height) of the calcaneus distal to the articular facets (78A), was found to be greater in Europeans as well. Table 12 contains a summary of the variables in numerical order along with their unstandardized coefficients and Function Four's constant.

Table 12. Unstandardized coefficients of Function Four predicting European ancestry from African ancestry.

Measurement	**Unstandardized Discriminant Function Coefficients**
74F (X_1)	0.259
78A (X_2)	0.190
80F (X_3)	-0.428
Constant	2.171

The complete discriminant function created using stepwise analysis is the following:

$$\text{Discriminant score (D)} = 0.259(X_1) + 0.190(X_2) - 0.428(X_3) + 2.171$$

A calculated discriminant score greater than the function cutoff point of -0.067, the mean of African and European scores, suggests an individual having European ancestry while one that is lesser than the mean has a higher likelihood of African ancestry. Forty-nine Europeans and 33 Africans had all three measurements necessary for the discriminant function analysis providing a total sample size of 82 individuals. Europeans classified better than Africans at 83.7% upon original analysis and after cross-validation. Africans were found to classify with 75.8% accuracy once function results were cross-validated. The probabilities of each ancestral group membership for this function's analysis can be found in Table 13.

Table 13. Probabilities of ancestral group membership from lower limb and foot measurements.

			Predicted Group Membership		
		Ancestry	European	African	**Total**
Original	Count	European	41	8	49
		African	8	25	33
	%	European	83.7	16.3	100.0
		African	24.2	75.8	100.0
Cross-validated	Count	European	41	8	49
		African	8	25	33
	%	European	83.7	16.3	100.0
		African	24.2	75.8	100.0

80.5% of original grouped cases correctly classified.
Cross-validation is done only for those cases in the analysis. In cross-validation, each case is classified by the functions derived from all cases other than that case.
80.5% of cross-validated grouped cases correctly classified.

Like the previous analyses of Korean and African/European ancestry, functions were created of different skeletal regions and their combinations to determine African and European ancestry, two of which were explained in detail as Functions Three and Four. However, instead of 15 functions like those created in the analysis of Korean ancestry and African/European ancestry, only 14 functions could be synthesized from postcranial measurements. A stepwise analysis of the lower limb did not yield a discriminant function as no measurements of this skeletal region were found to be significant in classifying Africans from Europeans without being analyzed with measurements from other skeletal regions. As such, no classification percentages or cross-validation percentages were calculated despite a sample size of 46 Europeans and 32 Africans with all lower limb measurements that had been selected for analysis. The results of all African and European ancestral discriminate analysis can be found in Table 14. Since no function could be created in this part of the analysis using only lower limb measurements, the correct classification percentages and cross-validated percentages for each ancestral group are listed as N/A, but the number of individuals from each ancestry that were evaluated by stepwise discriminant analysis are listed.

Europeans tended to correctly classify with greater than or equal to 72% accuracy. Only the function examining hand measurements, upper limb measurements, and upper and lower limb measurements fell below this percentage with the hand having the lowest accuracy of 63.2%. With cross-validation, Europeans classify with 72% accuracy or greater in all but four functions. The highest cross-validated percentage was found using Function Four at 83.7%, while the lowest was for the function derived from hand measurements at 61.4%.

Africans were slightly more likely than Europeans to misclassify in functions overall. Of the 14 viable functions, 10 correctly classified African individuals with 68% accuracy or greater. The lowest classification rate was seen in the function derived from upper and lower limb measurements at 65.7%. While the classification rates may not be as strong as those of European individuals, the range of classification accuracy is smaller. When all the functions were cross-validated, the lowest classification rate was still 65.7%, but it was found in the function created from upper and lower limb measurements as well as the upper limb measurements alone. The rest of the functions, save two, had cross-validation percentages of 67.6% or higher with the best classification of African ancestry coming from the combination of hand and foot measurements.

Table 14. Results of all European and African discriminant analysis.

Skeletal Region	European	African	Correct Classification % (European)	Correct Classification % (African)	Cross-Validation % (European)	Cross-Validation % (African)
Upper Limb	57	35	75.4	68.6	75.4	65.7
Hand	57	34	63.2	73.5	61.4	67.6
Pelvis	50	31	72.0	67.7	72.0	67.7
Lower Limb	46	32	N/A	N/A	N/A	N/A
Foot	53	35	77.4	77.1	73.6	74.3
Upper Limb, Lower Limb	61	35	65.6	65.7	65.6	65.7
Upper Limb, Hand	57	34	64.9	73.5	63.2	73.5
Hand, Foot	49	35	75.5	82.9	75.5	82.9
Upper Limb, Pelvis	47	30	76.6	73.3	74.5	73.3
Upper Limb, Pelvis, Femur	47	31	78.7	80.6	78.7	77.4
Upper Limb, Pelvis, Lower Limb	42	30	76.2	73.3	69.0	70.0
Pelvis, Femur	50	31	72.0	67.7	72.0	67.7
Pelvis, Lower Limb	48	31	72.9	66.8	74.2	71.0
Pelvis, Lower Limb, Foot	39	30	79.5	83.3	79.5	80.0
Lower Limb, Foot	49	33	83.7	75.8	83.7	75.8

Each discriminant analysis was performed using stepwise analysis to minimize the measurements needed to differentiate significantly the African and European ancestral groups. The details for each region's function can be found in Table 15. The measurements deemed the most significant for each function are listed in Table 16. No measurements are listed for the lower limb as none were deemed significant enough by stepwise discriminant analysis to distinguish African individuals from European individuals. To show that this skeletal region analysis was attempted, it is included in Table 16, but since it was not possible to create a function from these measurements and no cutoff point to differentiate between ancestries could be calculated, each entry for the lower limb function is listed as N/A. Of the measurements chosen during analysis, eight measurements were employed in multiple functions while nine were included only in a single function. The maximum breadth of the sacrum (55J) was found to be the most commonly utilized, followed by the maximum length of the cuboid (80F), the minimum diameter of the radial diaphysis distal to the radial tuberosity (47C), the maximum anterior-posterior distance of the distal articular surface of the tibia (74F), and the minimum breadth (height) of the calcaneus distal to the articular facets (78A). More measurements were found to be significant in the pelvis, lower limb, and foot than in the upper limb and hand. The frequencies of all measurements used to distinguish European and African ancestry can be found in Figure 9.

Table 15. Summary of all discriminant functions to differentiate between Africans and Europeans for each skeletal region.

Discriminant Function of Each Skeletal Region		
	Upper Limb	
	Discriminant score (D) = -0.325(41A) + 1.66(51A) + 1.556	
Cutoff: 0.0865	Above: African	Below: European
	Hand	
	Discriminant score (D) = -0.396(52.5B) + 0.549(52.5D) - 4.802	
Cutoff: 0.0765	Above: African	Below: European
	Pelvis	
	Discriminant score (D) = 0.128(55J) - 14.845	
Cutoff: -0.1185	Above: European	Below: African
	Lower Limb	
	Discriminant score = N/A	
Cutoff: N/A	Above: N/A	Below: N/A
	Foot	
	Discriminant score (D) = 0.296(78A) + 0.180(79A) - 0.117(80C) - 0.371(80F) + 1.467	
Cutoff: -0.162	Above: European	Below: African

Discriminant Function of Each Skeletal Region		
	Upper Limb, Hand	
	Discriminant score (D) = -0.381(52.5B) + 0.540(52.5D) - 5.301	
Cutoff: 0.0365	Above: African	Below: European
	Upper Limb, Lower Limb	
	Discriminant score (D) = 1.228(47C) - 0.324(68D) - 2.898	
Cutoff: 0.063	Above: African	Below: European
	Upper Limb, Pelvis	
	Discriminant score (D) = -0.479(47B) + 0.098(55J) + 0.118(59D) - 10.513	
Cutoff: -0.1325	Above: European	Below: African
	Upper Limb, Pelvis, Femur	
	Discriminant score (D) = -0.730(47C) + 0.084(55J) + 0.112(59D) - 8.738	
Cutoff: -0.1175	Above: European	Below: African
	Upper Limb, Pelvis, Lower Limb	
	Discriminant score (D) = -0.788(47C) + 0.106(55J) + 0.127(74F) - 7.502	
Cutoff: -0.0935	Above: European	Below: African
	Hand, Foot	
	Discriminant score (D) = 0.241(52.5E) - 0.312(78A) - 0.202(78B) + 0.279(80F) - 0.907	
Cutoff: 0.084	Above: African	Below: European
	Pelvis, Femur	
	Discriminant score (D) = 0.127(55J) - 14.744	
Cutoff: -0.1125	Above: European	Below: African
	Pelvis, Lower Limb	
	Discriminant score (D) = 0.145(55J) - 0.236(68A) - 10.340	
Cutoff: -0.077	Above: European	Below: African
	Pelvis, Lower limb, Foot	
	Discriminant score (D) = 0.119(55J) + 0.228(74F) - 0.395(80F) - 4.700	
Cutoff: -0.037	Above: European	Below: African
	Lower Limb, Foot	
	Discriminant score (D) = 0.259(74F) + 0.190(78A) - 0.428(80F) + 2.171	
Cutoff: -0.067	Above: European	Below: African

Table 16. Significant measurements of Europeans and Africans as determined by forward stepwise analysis.

Skeletal Region	Measurements in Final Equation
Upper Limb	41A, 51A
Hand	52.5B, 52.5D
Pelvis	55J
Lower Limb	N/A
Foot	78A, 79A, 80C, 80F
Upper Limb, Lower Limb	47C, 68D
Upper Limb, Hand	52.5B, 52.5D
Hand, Foot	52.5E, 78A, 78B, 80F
Upper Limb, Pelvis	47B, 55J, 59D
Upper Limb, Pelvis, Femur	47C, 55J, 59D
Upper Limb, Pelvis, Lower Limb	47C, 55J, 74F
Pelvis, Femur	55J
Pelvis, Lower Limb	55J, 68A
Pelvis, Lower Limb, Foot	55J, 74F, 80F
Lower Limb, Foot	74F, 78A, 80F

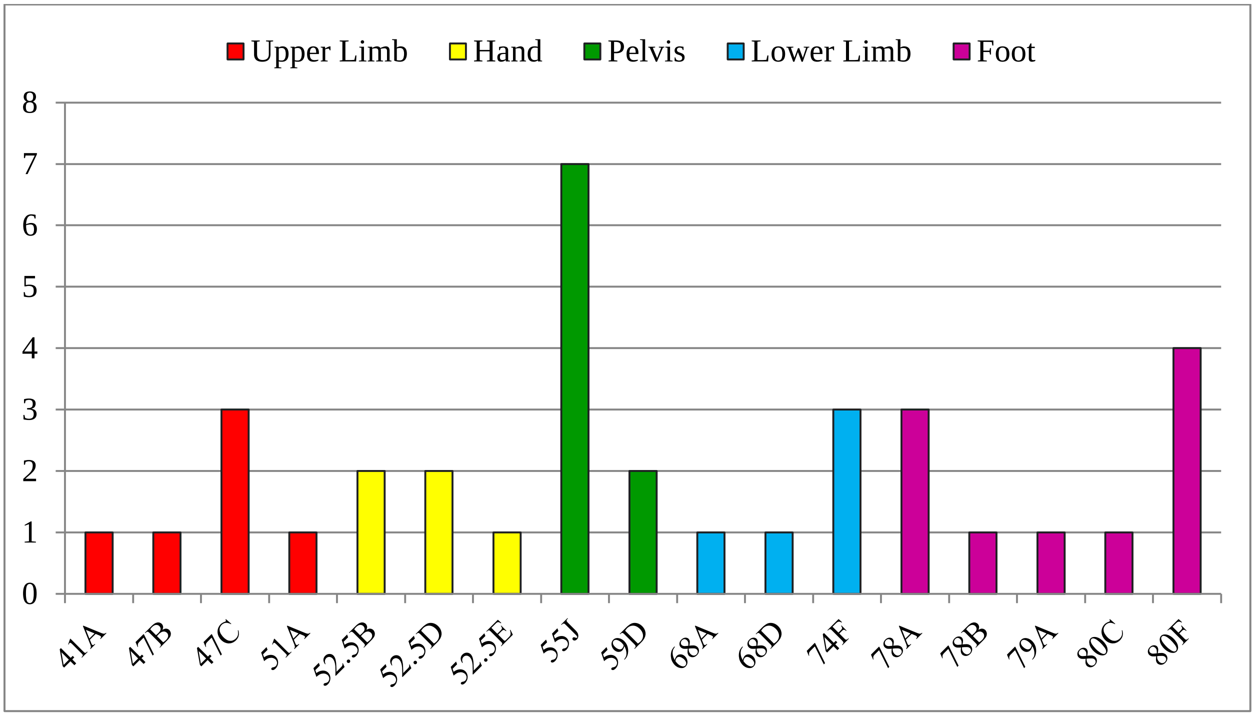

Figure 9. Significant measurements and their frequency of use to distinguish Europeans from Africans.

The three ancestral groups were analyzed in a two-part process: Korean or African/European and African or European. This approach was taken as initial discriminant analyses had lower classification percentages when all three groups were compared and had higher misclassifications. By creating multiple discriminant functions focused on particular skeletal regions and region combinations, it is possible to determine the most significant measurements should skeletal remains recovered by anthropologists be isolated to a particular skeletal region. As the measurements do not require complete bones, ancestral assessment can be attempted on fragmentary remains. Figure 10 combines the measurements determined to be significant for classifying Koreans from Africans/Europeans and Africans from Europeans. By depicting the frequency of the measurements together, it is possible to determine the most commonly used measurements for discriminant analysis, the measurements used to distinguish Koreans from Africans/Europeans and Europeans from Africans, as well as the measurements that can be used to distinguish all three ancestral groups.

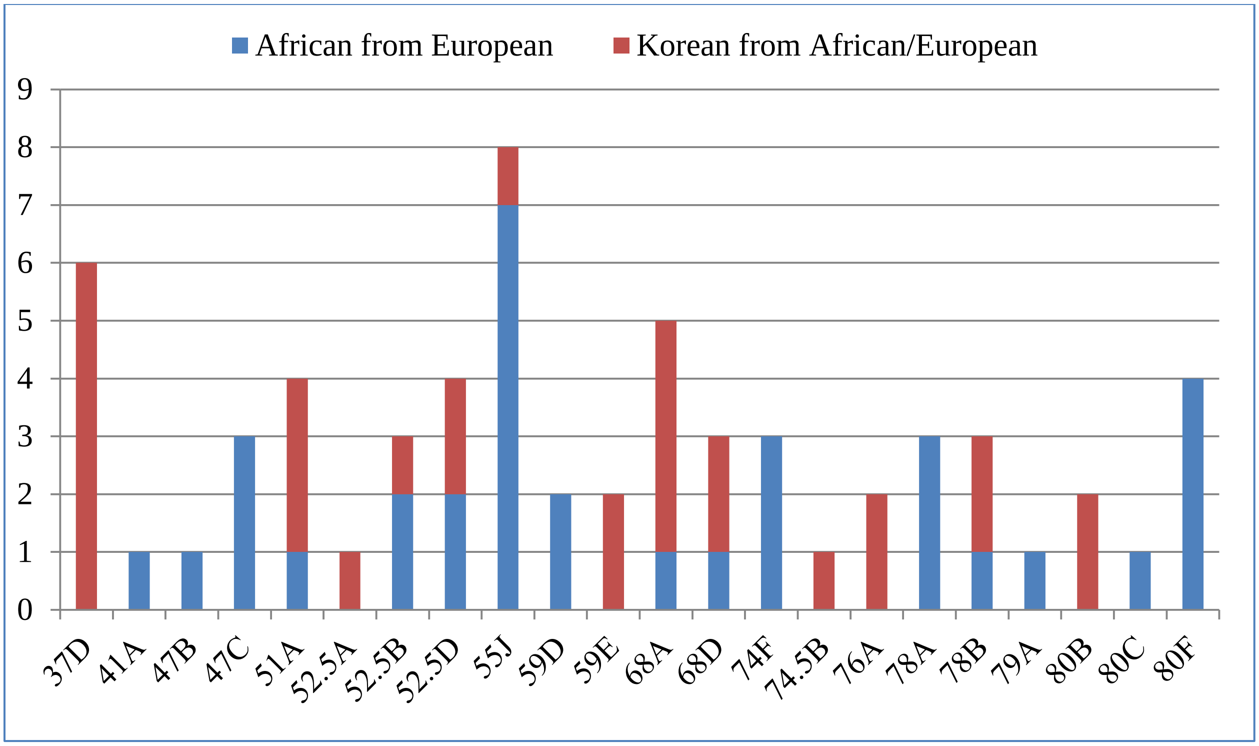

Figure 10. Significant measurements and their frequency of use to distinguish ancestries.

The maximum width of the clavicle at the proximal end (37D) was used repeatedly to differentiate Koreans from Africans/Europeans, and the maximum length of the cuboid (80F) was used repeatedly to distinguish Africans from Europeans. While both of these measurements have great significance in discriminating ancestral groups, they are binary and are not found to be significant in the discernment of all three possible ancestries. Six measurements were deemed significant in the analysis of all three ancestries. These measurements that were included in functions from both parts of the discriminant analysis come from the hand, sacrum, and femur.

CHAPTER FIVE: DISCUSSION

Discussion

Of the previous studies reviewed in Chapter Two, only a few have examined the genetic and environmental influences on the bones that were under analysis and how these factors may affect the traits being measured (Gilbert, 1976; Wescott, 2005; Wescott, 2006; Wescott and Srikanta, 2008). While methods have been created to classify a wide spectrum of skeletal elements using osteometrics and discriminant analysis, most extensively focus on the femur with particular emphasis on the subtrochanteric shape of the proximal end. The investigation of potential factors influencing features used for ancestral determination is key when developing a method that can be successfully replicated for correct classification, as features that reflect environmental plasticity have little use in ancestral identification (Wescott, 2005). By testing methods that show promise in differentiating individuals of different geographical ancestries for the degree of: variation within ancestral populations and between ancestral populations, temporal and geographic homogeneity of an ancestral group, sexual dimorphism, and physical activity related to lifestyle; it is possible to establish which analyses reliably report ancestry based on primarily genetic characteristics (Wescott, 2005; Wescott and Srikanta, 2008). These influences on morphological features, breadths, and diameters measured using osteometric sorting measurements were not assessed in this study as it is the first attempt of using these measurements to predict ancestry. Future research will explore the degree to which genetics and/or environment influence these measurements.

In this study, forward stepwise discriminant analysis was used to determine the most significant measurements for ancestry classification and to create functions for each postcranial skeletal region and region combinations that might be recovered by anthropologists for identification. In an effort to maximize the overall classification for all ancestral groups and minimize result inflation, analyses were broken into two parts: one examining Korean and African/European ancestry and the other examining African and European ancestry. A total of 15 functions were synthesized for the classification of Korean and African/European ancestry, while only 14 were developed for the differentiation of African and European ancestry as no significant differences were found in the analysis of the lower limbs alone.

The measurements determined to be the best at differentiating whether an individual is of Korean ancestry or African/European ancestry come from the upper limb. A summary of Discriminant Function One listing the most significant measurements, the function itself, and an interpretation of the function's cutoff point can be found in Table 17. In all functions that included measurements from the upper limbs, the maximum width of the clavicle at the proximal end (37D) always was among the most significant, if not the only significant, differentiating measurement with Koreans consistently having a smaller short axis of the oval sternal end than Africans or Europeans. It is also found in Function Two, which has the second highest overall classification for Korean and African/European ancestry. A summary of the upper limb and hand measurements employed and other relevant information can be found in Table 18.

Table 17. Summary of Discriminant Function One for classification as Korean or African/European using upper limb measurements.

Discriminant score = 0.357(37D) – 0.368(51A) – 5.244	
Measurement	Maximum Width of the Clavicle at the Proximal End (37D) Minimum Diameter of the Ulnar Diaphysis including the Interosseous Crest (51A)
Cutoff Point	-0.955 Above: African/European Below: Korean

Table 18. Summary of Discriminant Function Two for classification as Korean or African/European using upper limb and hand measurements.

Discriminant score = 0.274(37D) – 0.545(51A) + 0.112(52.5D) – 7.788	
Measurement	Maximum Width of the Clavicle at the Proximal End (37D) Minimum Diameter of the Ulnar Diaphysis including the Interosseous Crest (51A) Maximum Length of the 4th Metacarpal (52.5D)
Cutoff	-1.057 Above: African/European Below: Korean

The two functions found to have the highest classification rates for differentiating Korean ancestry from African/European also happen to be two of the functions with the smallest Korean sample size. As a smaller sample size could skew the synthesized discriminant functions, the osteometric sorting measurements of the individuals included in the analyses were compared to the mean of each significant measurement in the two best classifying functions. Each of the Koreans that helped create the upper limb function and the upper limb and hand function were found to have measurements equal to or slightly larger than the mean of each osteometric sorting measurement. This suggests that, while the Korean samples sizes of these two functions were small, the individuals chosen for analysis based on measurement completeness are good representations of the Goyang sample.

A bigger sample size in future studies will help prevent possible skewing of discriminant functions and will also allow for the effects of sexual dimorphism in the Korean population to be assessed. This study's Korean sample population is predominantly male and is two times as large as the female ancestral population. As sexual dimorphism could have had an effect on the correct classification of Korean individuals and the functions from the first part of the discriminant analysis, additional discriminant analyses were performed using the same measurements from each function with the measurements being entered independently instead of stepwise into the discriminant analysis. Since measurements were entered into the analysis independently, all the measurements found to be significant in stepwise analysis were included in the resulting discriminant function which allowed for the sex of individuals used in the stepwise analysis to be examined. All functions had a greater number of males than females contributing to the analysis. While the functions created using only the significant measurements entered independently did not have the same function coefficients, most were similar. The male functions were found to classify at rates similar to the functions created with the sexes pooled, while the females were found to classify favorably in almost all of the functions. This higher rate of classification for females is likely due to the extremely small samples used for analysis. The similarities between the male classification accuracy and the stepwise discriminant functions of this study support the hypothesis that the larger male population influenced the analysis to favor more masculine measurements.

The larger Korean male population could also affect which measurements were found to be significant. In Function One and Function Two, the minimum diameter of the ulnar diaphysis (51A) stood out in both structure matrices. This measurement, like all of osteometric sorting measurements, was smaller in Koreans than in Africans and Europeans, but because of its positive structural association to the Korean sample, it is possible that this could be a proportional or shape difference between the ancestries. It could also be influenced by environmental factors unique to the later Joseon dynasty, such as occupation and physical labor.

Many of the Koreans in this historical era were involved in agriculture, carpentry, or stone masonry (Choy, 1971). With the improvement of cultivation techniques in the 17th century, more individuals farmed larger pieces of land than they had previously (Lee, 1984) in a practice referred to as "enlarged scale farming" or kwangjak (광작) (Lee, 1984:227). One of the technological advances at this time was the introduction of the plow, which supported the cultivation of larger fields with less effort (Lee, 1984). It is possible that the differences found between the upper limb measurements and the combination of upper limb and hand measurements are environmentally influenced as more intensive physical activity involving these parts of the body is likely to create greater robusticity of muscle attachments and the areas around them.

The best way to determine the influence genetic and environmental factors have on the Korean osteometric sorting measurements would be to compare the Goyang individuals to modern Korean individuals. Secular change has been noted in the population, particularly in terms of stature (Shin et al., 2012), but additional information about other skeletal changes are hard to come by. If the measurements that were found to be significant for the Koreans in this study are also found to be of similar size and significance, then it is likely that the differences highlighted in the discriminant analysis are related to population proportions and shape which are influenced by genetics. However, if the measurements, particularly the ulnar measurement (51A), are found to differ in the modern population, then environment could have been a considerable factor.

If Korean ancestry has been ruled out and an anthropologist is endeavoring to distinguish an individual's ancestry as African or European, measurements from the pelvis, lower limbs, and feet were found to have the best discrimination between the two ancestries. The combination of pelvis and lower limb measurements have been found to have the highest classification accuracies when comparing individuals of African and European ancestry in other studies as well (Dibennardo and Taylor, 1983; İşcan and Cotton, 1990). It has been suggested that the discriminant analysis of the two regions together allows for the evaluation of noted ancestral differences in limb and torso proportions (Dibennardo and Taylor, 1983). This study is unique in the addition of foot measurements to the analysis of the pelvis and lower limbs, but it is likely that the proportional differences in the limbs found to be useful in previous discriminant analysis studies are present in the length and size of the feet as well allowing for increased classification accuracy. While other studies' discriminant functions for this combination of pelvis and lower limbs use many measurements, Function Three contains only three measurements; one from each skeletal region, all repeatedly found to be significant in other discriminant analyses with the maximum breadth of the sacrum (55J) being the most significant of all postcranial measurements when examining African and European ancestry. A summary of Function Three can be found in Table 19 along with the function's cutoff point.

Table 19. Summary of Discriminate Function Three for classification as African or European using pelvis, lower limb, and foot measurements.

Discriminant score = 0.119(55J) + 0.228(74F) - 0.395(80F) - 4.700	
Measurement	Maximum Breadth of the Sacrum with the Osteometric Board (55J) Maximum Anterior-Posterior Distance of the Distal Articular Surface of the Tibia (74F) Maximum Length of the Cuboid (80F)
Cutoff	-0.037 Above: European Below: African

Measurements of the lower limb and foot had the second highest classification rate as found in Function Four, which is summarized in Table 20. The maximum anterior-posterior distance of the distal articular surface of the tibia (74F) and the maximum length of the cuboid

(80F) were also utilized in Function Three. Since two of the measurements found to be significant in Function Three were are also included in Function Four, it is likely that the underlying proportional differences between the limbs of Africans and Europeans are at play in this function as well. While measurements of the lower limb were found to be significant when other skeletal regions were available for analysis, by themselves none stood out as significant in stepwise analysis making the creation of a discriminant function based on these measurements alone impossible. Other studies examining the postcranial ancestry were able to create discriminant functions differentiating Africans from Europeans using only lower limb measurements, but the classification accuracies were much lower than when the limb measurements were combined with a different skeletal region such as the pelvis (İşcan and Cotton, 1990). As no lower limb function could be created in this study using stepwise discriminant analysis, it is hard to predict how well the measurements alone could have predicted ancestry had a function been created.

Table 20. Summary of Discriminant Function Four for classification as African or European using lower limb and foot measurements.

Discriminant score = 0.259(74F) + 0.190(78A) - 0.428(80F) + 2.171	
Measurement	Maximum Anterior-Posterior Distance of the Distal Articular Surface of the Tibia (74F) Minimum Breadth(Height) of the Calcaneus Distal to the Articular Facets (78A) Maximum Length of the Cuboid (80F)
Cutoff	-0.067 Above: European Below: African

In this study, Africans and Europeans tended to have lower overall classification rates for each discriminant analysis when compared to the Korean classification rates. By having larger sample populations for analysis, more variation was present in the African and European groups than was in the Korean sample. This allowed the discriminant functions in the first part of the ancestral discriminant analysis to better classify the smaller more homogenous Korean individuals, while still classifying the larger pooled African/European sample moderately well. As size played a considerable part in the correct classification of individuals in this study, similarities in body size greatly contributed to correct classification of Africans/Europeans, but once the discriminant analyses were only focused on the classification of Africans from Europeans this similarity in size contributed to the predicted membership percentages for each group falling below that of the pooled analyses of the same skeletal regions and region combinations.

Of the two groups, Europeans had higher overall classification rates than Africans. Part of this difference in classification accuracy can be attributed to the larger European sample size used in analysis, and part of the higher African misclassification rate can be attributed to the genetic heterogeneity of the African American population (Duray et al., 1999). A larger sample of more genetically homogenous individuals of European ancestry would be at a slight advantage in stepwise discriminant analysis, as the functions synthesized will be better fitted to the larger sample group. The genetic variation in the African American sample population would increase the likelihood of individuals having similar osteological features to the other ancestral populations that are a part of the individual's background, the most common being European followed by Native American (Duray et al., 1999). As the African American sample was being compared to individuals of European ancestry, these osteological similarities will influence the osteometric sorting measurements collected and lead to more Africans classifying as European in discriminant analysis.

Other postcranial studies have noted higher misclassification rates for African Americans when attempting to predict African ancestry from European ancestry (Duray et al, 1999; Trudell, 1999). Since most of the study collections used for research are composed of remains that were labeled according to their "racial" group at the time of death based solely on the appearance of the individual's soft tissue (Duray et al., 1999; Wedel, 2007; Byers, 2008), this misclassification trend is likely to continue occurring in future studies. However, bigger, more equally matched sample sizes of African and European ancestry will help minimize any bias one sample can place on the synthesized discriminant functions during analysis as both groups will have equal representation for each significant osteometric sorting measurement.

An additional factor that may have skewed the classification rates of each discriminant analysis as well as the osteometric sorting measurements found to be significant could be the sex of the individuals analyzed. Because the population sizes of African and European ancestry were already small once all individuals lacking measurements for the region or regions being analyzed were excluded, both sexes were pooled together to create viable ancestral samples for analysis. As each ancestral population had more males than females, it is possible that they could have skewed the discriminant functions in favor of the more masculine osteometric sorting measurements of that ancestral group.

When differentiating between Korean and African/European ancestry and later between African and European ancestry, forward stepwise discriminant function analysis was used. From these pooled male and female populations for each ancestry, certain measurements were deemed to be the most significant in differentiating between groups based on the skeletal region or region combinations under analysis. Recognizing the possible role sexual dimorphism could have had on the correct classification of this study's African and European individuals, additional discriminant analyses were performed using the same measurements from each function with the measurements being entered independently instead of stepwise into the discriminant analysis. By entering the measurements independently, all the measurements found to be significant in stepwise analysis were included in the resulting discriminant function allowing for the sex of individuals used in the stepwise analysis to be examined. All functions were found to have a greater number of males than females contributing to the analysis. While the functions created using only the significant measurements entered independently do not have the same function coefficients, most are similar. Most male functions were found to classify similarly well as those of the functions created with the sexes pooled, while the females were found to classify favorably in half of the functions and less favorably in the other. This suggests that the discriminant functions created in this study from pooled male and female populations of African ancestry and European ancestry may be slightly skewed to favor correct classification in males. This is something that will have to be addressed in future research.

Another goal of this study was to determine which postcranial measurements were the most beneficial in differentiating ancestry. The biggest differences seen between Koreans and African/Europeans can be attributed to size. All Korean measurements were found to be smaller, but, additionally, there may be a possible proportional difference between individuals of Korean ancestry and African/European in the upper limbs as the minimum diameter of the ulnar diaphysis (51A) was denoted as slightly larger in all the discriminant function structure matrixes in which it was included for analysis. This difference could be environmental as the lifestyle and activities of Koreans living in the later part of the Joseon dynasty are not the same as those of individuals of African or European ancestry in the United States currently or at the beginning of the 20th century. However, further testing needs to be completed to better explain this ulnar measurement and determine the possibility of proportional or shape differences. Moreover, the addition of a modern Korean sample to the study would help clarify the effects of secular change, genetics, and environment when analyzing all the osteometric sorting measurements as well as the ulnar measurement.

By combining the z-scores of all of the osteometric sorting measurements collected from a particular individual to create a mean z-score for that individual, it was possible to compare the body size of all three ancestral groups against each other as the data became standardized. Individual mean z-scores helped express an individual's number of standard deviations smaller or larger from the average body size of the entire sample population. Most of the Koreans were found to be at least a half standard deviation or greater below the group mean supporting the hypothesis that Koreans have a smaller overall body size which results in smaller osteometric sorting measurements. Individuals of African or European ancestry tended to have similar z-scores above the group mean which supports these two ancestries having similar overall body sizes and similar osteometric sorting measurement means.

A total of 12 measurements were determined to be significant in these analyses which are as follows: maximum width of the clavicle at the proximal end (37D); minimum diameter of the ulnar diaphysis including the interosseous crest (51A); maximum length of 1st metacarpal (52.5A), 2nd metacarpal (52.5B), and 4th metacarpal (52.5D); maximum breadth of the sacrum with an osteometric board (55J); maximum diameter of the acetabulum (59E); minimum anterior-posterior diameter of the femoral diaphysis (68A); minimum superior-inferior femoral neck diameter (68D); maximum diameter of the fibular diaphysis (76A); posterior length of the calcaneus (78B); and maximum length of the 2nd metatarsal (80B). Of these measurements, the maximum width of the clavicle at the proximal end (37D) was most significant, followed by the minimum anterior-posterior diameter of the femoral diaphysis (68A) and the minimum diameter of the ulnar diaphysis (51A).

While size greatly influenced the classification of Koreans and African/Europeans in the first part of the discriminant analysis, proportionality is likely to have played a greater role in differentiating Africans and Europeans. While both ancestries have similar larger body sizes, Africans tend to have longer limbs and narrower torsos than Europeans (Holliday and Falsetti, 1999). Conversely Europeans tend to have broader torsos which are supported by more robust limbs (Holliday and Falsetti, 1999). The measurements displaying the biggest differences between Africans and Europeans are more numerous than those found to differentiate Koreans, totaling 16. Eight were used in more than one function: minimum diameter of the diaphysis distal to the radial tuberosity (47C), maximum length of the 2nd metacarpal (52.5B), maximum length of the 4th metacarpal (52.5D), maximum breadth of the sacrum with an osteometric board (55J), minimum breadth of the ilium from the sciatic notch (59D), maximum anterior-posterior distance of the distal articular surface of the tibia (74F), minimum breadth (height) of the calcaneus distal to articular facets (78A), and maximum length of the cuboid (80F).

Of these measurements used multiple times in functions, the maximum breadth of the sacrum with an osteometric board (55J) was used the most frequently and utilized in half of all the African and European functions. The second most frequently used measurement was the maximum length of the cuboid (80F). Europeans had the largest mean of all the groups when measuring the breadth of the sacrum, which could be related to a wider torso. This measurement is less influenced by environmental factors (İşcan, 1983), so individuals of the same background are likely to have similar measurements despite secular changes in the American population. The length measurements of foot bones are likely correlated to the length of the bones of the lower limbs, giving Africans with proportionally longer limbs longer feet. However, further tests are needed to definitively draw this conclusion from the current study's African sample population.

Interestingly, several measurements were significant in the determination of Korean and African/European ancestry and African and European ancestry. These measurements are: the minimum diameter of the ulnar diaphysis including the interosseous crest (51A), maximum length of the 2nd metacarpal (52.5B), maximum length of the 4th metacarpal (52.5D), maximum breadth of the sacrum with an osteometric board (55J), minimum anterior-posterior diameter of the femoral diaphysis (68A), and the minimum superior-inferior femoral neck diameter (68D). Of these measurements used in both parts of the ancestral discriminant function analysis, the long bone measurements (51A, 68A, and 68D) were used most frequently to differentiate Korean ancestry from African/European while metacarpal length and sacrum breadth were most useful in the discernment of African and European ancestry. As these six measurements were used in both parts of the analysis, it is likely that some shape and proportionality differences are being accounted for in the discriminant analysis. However, it is difficult to say with confidence how these measurements differ be it due to shape and/or proportionality.

When examining the mean of each ancestral population's measurements and performing discriminant analysis, parallels were found in the data that support previous research findings.

All Korean measurements in this study were found to be smaller than those of Africans and Europeans which has been supported by femoral and stature studies (Choi et al., 1997; Wescott, 2006). Although individuals in this study were not tested to compare their scores on the platymeric index (PI), two femoral measurements were found to be significant in multiple discriminant functions: the minimum anterior-posterior diameter of the femoral diaphysis (68A) and the minimum superior-inferior femoral neck diameter (68D). Studies of Native Americans and pooled populations of African/European ancestry have found differences in the proximal femur to be significant enough for classification of both groups to be made accurately (Wescott and Srikanta, 2008). As one, and possibly both, of the femoral measurements of this study can be found proximally with a larger minimum superior-inferior femoral neck diameter (68D) and smaller minimum anterior-posterior diameter of the femoral diaphysis (68A), osteometrics suggest a more oval diaphyseal shape in the Korean population. This would support other non-Native American populations of Asian ancestry being more platymeric than Africans or Europeans as has been found in Australian, Polynesian, Chinese, and Easter Island populations (Gill, 2001; Wescott and Srikanta, 2008).

Interestingly, the maximum width of the clavicle at the proximal end (37D) was the most significant measurement in differentiating Korean ancestry from African/European. Differences in the clavicle have been noted between African and European ancestry and are centered upon the acromial end and conoid tubercle. Africans were found to have a smaller sagittal diameter and smaller, sometimes absent, conoid tubercles in comparison to Europeans (Terry, 1932). The findings of this study suggest that the proximal end of the clavicle could be equally important in the determination of postcranial ancestry based on its frequent inclusion in discriminant functions. It is likely that the main reason that the measurement classifies Koreans from African/Europeans so well is due to differences in size, but there may be some underlying proportional differences which should be explored in future studies.

Of the other postcranial ancestry studies to date, most examine differences between European and African ancestry. Research has shown variation between the torso and lower limbs of both groups with most investigations centering on the pelvis and femur (Dibennardo and Taylor, 1983; İşcan, 1983; İşcan, 1990; İşcan and Cotton, 1990; Holliday and Falsetti, 1999). These ancestral differences in torso breadth and limb length have often been explained by Bergmann's rule and Allen's rule. According to Bergmann's rule, a mammal's size and shape are determined by heat loss and the balancing of volume and surface area. As a mammal of greater size has a smaller surface area to volume ratio, it will lose heat more slowly than a mammal of similar shape but smaller size (Mielke et al., 2006). This has been applied to humans to explain the general stocky robustness of European individuals in comparison to the more gracile and elongated bone structure of African individuals with a particular focus on the pelvis as it exemplifies torso breadth (Holliday and Falsetti, 1999; Mielke et al., 2006). Allen's rule applies to the length of the limbs with warm temperatures leading to the preference of long limbs and colder temperatures to shorter limbs (Holliday and Falsetti, 1999; Mielke et al., 2006).

Focusing on pelvis measurements, Europeans in this study were found to have the largest breadths and diameters in comparison to Koreans and Africans. This could support Bergmann's rule, as larger measurements suggest more robust bone and a larger overall body size. Of the pelvic measurements, the maximum breadth of the sacrum (55J) was found to be greatly significant when differentiating between African and European ancestry. This indication of greater torso breadth is bolstered by the significance of the greater mean minimum breadth of the ilium from the sciatic notch (59D) in Europeans which would be necessary to support greater body weight for height (Holliday and Falsetti, 1999).

In this study, Africans were found to have slightly larger mean long bone diaphyseal diameter/breadth measurements than Europeans. This observation, having been found in the femur, is attributed to the lack of anterior femoral curvature in Africans as an increase in diameter and thicker cortex make it more resistant to bending (Walensky, 1965). Measurements of the limbs by themselves do not classify as accurately as they do when combined with pelvic measurements (Dibennardo and Taylor, 1983; İşcan and Cotton, 1990) and in this study were unable to be classified at all due to lack of significant measurements. Of the lower limb measurements deemed to be significant when combined with pelvic or foot measurements, two were from the femur (68A and 68D) and one was from the distal end of the tibia (74F). While measurements were not taken of the maximum lengths of the long bones, the length of bones in the hands and feet were measured and are likely related to the proportions of the limbs. The mean maximum lengths of this study's Korean and European metacarpals and metatarsals are shorter than those of the African population which could support Allen's rule if found to be true for the long bone lengths. These proportional differences should be considered in future studies through the analysis of bone shape.

Previous Research

Limited postcranial research has been performed on individuals of Native American (Asian) ancestry. In the studies that have been done, a majority focus on the femur with a strong emphasis placed on the subtrochanteric shape (Gilbert and Gill, 1990; Wescott, 2005; Wescott, 2006; Wescott and Srikanta, 2008). Differences in the proximal femoral diaphysis were originally only used to visually differentiate Native American remains from those of African or European ancestry (Gilbert and Gill, 1990), but the metric analysis of this area using the platymeric index (PI) proved to be useful in differentiating Native Americans (Gilbert and Gill, 1990; Gill and Rhine, 1990) and other Asian ancestries (Wescott, 2005; Wescott and Srikanta 2008) from those of African or European ancestry. Gilbert and Gill's (1990) sectioning point allowed for all individuals in their pooled population of African/European ancestry to be correctly classified, but only classified 61% of the Native Americans correctly. In an attempt to better classify the Native American group, Gill and Rhine (1990) added an appendix to Gilbert and Gill's original study published in *Skeletal Attribution of Race* which analyzed a larger Native American sample against a European sample. The new sectioning point allowed for both groups to correctly classify with over 78% accuracy (Gill and Rhine, 1990).

More recent platymeric index studies have been completed that examine the variation within populations and between populations to determine how much of the subtrochanteric shape of the femur is determined by genetic and environmental factors (Wescott, 2005), the development of the subtrochanteric shape (Wescott, 2006), and the testing of Gilbert and Gill's assumptions using multiple ancestral populations (Wescott and Srikanta, 2008). All of these studies have been found to classify well with similar accuracies for Africans/Europeans and Native American (Asian) ancestry. The classification results of several previous postcranial studies that differentiate Native American (Asian) ancestry from African and European ancestry can be seen in Table 21. The classification rates of this study are also included in the table. While some of the discriminant functions in this study are shown to have lower percentages in classifying Koreans and African/Europeans, most of the function results were found to be comparable to the rates of other studies.

Table 21. Classification results for previous postcranial studies that compare Native American ancestry from a pooled population of African/European ancestry as well as the classification results of this study for Korean ancestry.

Study	African/European Classification Rates		Native American (Asian) Classification Rates	
	Males	Females	Males	Females
Gilbert and Gill, 1990	100%		61%	
Gill and Rhine, 1990	85%		78.33%	
Wescott, 2005	75.4%-79%	72.6%-83.1%	71.7%-80.4%	81.6%-86.7%
Wescott, 2006	85.40%		85.40%	
Wescott and Srikanta, 2008	79%		77%	
Okrutny, 2012	66.7%-89.2%		64.7%-93.3%	

The number of studies that compare the postcranial morphological differences between African and European ancestry is more numerous than the previously discussed Native American studies. The skeletal elements analyzed are also more diverse with the examination of the cervical vertebrae (Marino, 1997; Duray et al., 1999), hyoid (Kindschuh et al., 2012), pelvis (İşcan, 1983; Taylor and Dibennardo, 1984), and lower limbs (Baker et al, 1990; Craig, 1995; Trudell, 1999) as well as the combination of the pelvis and lower limbs (Dibennardo and Taylor, 1983; İşcan, 1990; İşcan and Cotton,1990; Holliday and Falsetti, 1999). Of these postcranial methods, the best classifications for individuals of African or European ancestry come from the discriminant analysis of the pelvis with a bone or bones from the lower limb. The increased power of differentiation from these functions lies in the ability of the multivariate analysis to express ancestral proportional differences that have be documented in the length of the limbs and torso (Dibennardo and Taylor, 1983). The method with the least success examined the possibility of spontaneously determining ancestry and sex from the central portion of the innominate with accuracies between 58.5% and 64.6% (Taylor and Dibennardo, 1984).

This study had similar trends in the successful classification of Africans and Europeans. Function Three of pelvis, lower limb, and foot measurements was the best classifying discriminant function in the second part of the ancestral discriminant analysis with cross-validated accuracies of 79.5% in Europeans and 80% in Africans. The function created using osteometric sorting measurements from the pelvis was found to classify better (72% for Europeans and 67.7% for Africans) than Taylor and Dibennardo's (1984) ancestral analysis of the innominate, but part of this is likely due to the pooling of the sexes in all of this study's analyses. The classification results of previous African and European postcranial studies can be seen in Table 22. The classification rates of this study are listed at the bottom of the table. While some of the discriminant functions in this study are shown to have lower percentages in classifying Africans and Europeans, most of the function results were found to be comparable to the rates of other studies if not higher.

Table 22. Classification results for previous postcranial studies that compare African and European ancestry as well as the classification results of this study.

Study	African Classification Rates		European Classification Rates	
	Males	Females	Males	Females
Dibennardo and Taylor, 1983	96.90%	92.30%	93.80%	96.90%
İşcan, 1983	76%-92%	76%-88%	80%-92%	60%-84%
Taylor and Dibennardo, 1984	64.60%	58.50%	63.10%	58.50%
Baker et al., 1990	79.16%	82.50%	76.92%	76.92%
İşcan, 1990	74%-80%	76.9%-82%	78.4%-86.3%	54%-70.6%
İşcan and Cotton, 1990	78.4%-96%	66.1%-94%	76%-95.8%	64.8%-87.5%
Craig, 1995	83%-90%		80.25%	
Marino, 1997	60%-76%			
Holliday and Falsetti, 1999	Males 81.8%-87%, Females 57.1%-100%			
Trudell, 1999	86.1%-88.15%			
Kindschuh et al., 2012	76%-78% Fused, 70-73% Unfused/Body Only			
Okrutny, 2012	65.7%-82.9%		61.4%-83.7%	

Testing of Korean Discriminant Functions with Modern Skeletal Remains

The 15 functions created in this study to differentiate Korean individuals from those of African or European ancestry could possibly be used to differentiate other Asian ancestries from those of African or European backgrounds. To test this hypothesis, two modern individuals (HR-003 and HR-005) of Chinese ancestry from the University of Central Florida’s (UCF) study collection were measured. When possible, the same osteometric measurement was collected on both sides of the body and then averaged before its input into a discriminant function from Table 8. If it was not possible to take the same measurement on both sides of the body, the single measurement from whichever side of the body was utilized in the discriminant function(s). The resulting discriminant scores for each study skeleton can be found in Table 23 along with the score’s classification.

Table 23. Discriminant scores and classification of the two UCF study skeletons for each function by skeletal region(s).

Discriminant Function by Skeletal Region(s)	HR-003 Discriminant Score	Correctly Classified as Korean (Asian)	HR-005 Discriminant Score	Correctly Classified as Korean (Asian)
Upper Limb	-1.68460	Yes	-1.06040	Yes
Hand	-0.23150	No	-0.52850	Yes
Pelvis	0.60400	No	-1.93700	Yes
Lower Limb	1.06480	No	-0.12770	No
Foot	-0.21280	No	-1.12400	Yes
Upper Limb, Hand	-1.40310	Yes	-1.00435	No
Upper Limb, Lower Limb	-1.39300	Yes	-0.80705	No
Upper Limb, Pelvis	-1.59500	Yes	-1.04240	Yes
Upper Limb, Pelvis, Femur	-1.57000	Yes	-1.01560	Yes
Upper Limb, Pelvis, Lower Limb	-1.51000	Yes	-0.97000	Yes
Hand, Foot	0.15030	No	-2.87220	Yes
Pelvis, Femur	-4.55590	Yes	-4.97120	Yes
Pelvis, Lower Limb	-0.74920	No	-0.65145	No
Pelvis, Lower Limb, Foot	-0.23730	No	-1.11500	Yes
Lower Limb, Foot	0.63730	No	-2.65090	Yes

While both of the study skeletons are of Chinese ancestry, there were some marked differences in the skeletons themselves and the measurements that could be collected. HR-003 was visibly the more robust of the two skeletons both cranially and postcranially. Most of its measurements were between two to seven millimeters larger than measurements taken from HR-005. The greatest range between the two individuals' measurements was in the posterior length of the calcaneus (78B) which differed by 14.6 millimeters.

Seven of the 15 discriminant scores for HR-003 correctly classified the individual as Asian, and 11 of the 15 discriminant scores for HR-005 correctly classified the individual as Asian. This means that HR-003 correctly classified with 46.7% accuracy while HR-005 correctly classified with 73.3% accuracy. As HR-003's measurements deviated from HR-005's measurements so considerably, the difference in classification accuracy is not surprising. However, it is interesting that both individuals classified the same way, be it correctly or incorrectly, in eight functions. The upper limb function, which was found to correctly predict Korean ancestry with the highest percentages, was also found to correctly classify the Chinese individuals as Asian. In fact, all but two of the functions that included the maximum width of the proximal end of the clavicle (37D) were found to correctly classify both individuals if all the necessary measurements for the function were gathered. Surprisingly, the function that classified both individuals the most strongly as Asian was composed of measurements of the pelvis and femur which was also found to have a high classification rate for differentiating Koreans from Africans/Europeans.

The lower overall classification rate for HR-003 could have been affected by the individual's robusticity. It could also be due to the functions being created from a different ancestral sample population than that to which the UCF skeletons belong. When a method has been created with a specifically focused dataset, caution should be exercised in analyzing populations for which the study was not originally designed (İşcan, 1983; Wescott, 2005; Wescott and Srikanta, 2008; Kindschuh et al., 2012). This is due to possible genetic and environmental differences that could be present in different geographical ancestries despite their shared continental ancestry. There is also a historical difference between the Korean collection from which the functions were synthesized and the two UCF study skeletons which brings to light the possible effects of secular change.

While HR-003 did not classify very well, HR-005 correctly classified using a majority of the Korean discriminant functions. Since one individual classified relatively well and the other slightly better than chance, a larger modern sample of Chinese ancestry is required before anything can be definitively determined for this test sample. HR-005 creates the possibility that the 15 Korean discriminant functions could be expanded to differentiate more Asian ancestries from African/European ancestry, but as it is a single individual, there is no good way to determine if the individual is representative of modern Chinese individuals or is a population outlier.

From these results, it appears that the maximum width of the clavicle's proximal end (37D), the maximum diameter of the acetabulum (59E), the minimum anterior-posterior diameter of the femoral diaphysis (68A), and the minimum superior-inferior femoral neck diameter (68D) could be proportionally similar in individuals of Korean ancestry and individuals of Chinese ancestry. This may be due to the size of the bones measured in comparison to those of African or European ancestry, or it also could be due to differences in shape. In order to determine whether the similarities between the two Asian ancestries lie in size or shape, further analyses will have to be completed, but based off of the current findings, the functions have the potential to be applicable to more Asian populations which would make them more useful in a forensic setting.

CHAPTER SIX: CONCLUSIONS

Based on the magnitude of the classification percentages for each ancestral group and the discernment of significant variables in each skeletal region, it is possible to differentiate between Korean, African, and European ancestries. In the first part of the discriminant analysis found in Chapter Four, it was determined that upper limb measurements best differentiated Koreans from Africans/Europeans while the second part of chapter four's analysis revealed that pelvic, lower limb, and foot measurements best separated Europeans and Africans. Examination of the significant osteometric sorting measurements demonstrates that most of the differences between ancestries are due to size which is supported by previous postcranial research.

Although other studies have been conducted to compare Asian ancestry with African and European ancestry, this is one of the few that uses a geographically Asian population collection. It also is unique in the analysis of the entire postcranial skeleton for the ancestry determination. By investigating the possible variation in a greater number of bones, it is possible for new methods to be discovered and to improve techniques already in use. Since remains are not always found with a skull and can be fragmentary, the search for new methods of ancestry determination is necessary to increase the likelihood of correct identification.

Limitations

Of the ancestral groups, Koreans tended to classify better than Europeans and Africans. However, the eigenvalues, Wilks' lambdas, and canonical correlations for the Korean and African/European analyses were not nearly as good as those found in the analyses of Africans and Europeans. Part of this could be attributed to the smaller Korean sample size in comparison to the separate and pooled African and European sample set. Additionally, the number of individuals analyzed in each discriminant analysis differed as not all measurements were present in all individuals. With the larger sample sizes of the Africans and Europeans, this flux in numbers might have minimal effects, but the decreasing of an already small Korean sample could influence the classification accuracy of each function and possibly drag the discriminant score cutoff point further from zero than it would if more individuals were accessible. Additional Korean individuals are needed to determine how much of an effect this may have had on classification results and should be factored into future research of this ancestry.

Secular change in all three ancestries was not accounted for in this study. These population changes have been found in the European and African individuals of the Terry collection when compared to corresponding individuals of the same ancestry in the Hamann-Todd collection (İşcan, 1990; Jantz and Jantz, 1999). These are more pronounced in the lower limbs and are most likely the result of differences in nutrition and disease between the time periods the collections were established (İşcan, 1990; Jantz and Jantz, 1999). As a large part of the European and a sizeable amount of the African sample consist of individuals from the Bass collection or FDB, the potential effect of secular change on this study's analyses of these two ancestries may be minimal as all individuals are modern. However, there is no modern Korean population in this study to compare against the historical Goyang collection or to offset the possible error this could introduce to analysis to the Korean ancestry analysis.

Compared to other historical populations during the latter part of the Joseon dynasty (1637-1897), Koreans males were documented as being 5-10 cm shorter than males in other Western cultures (Shin et al., 2012). Stature was not calculated for individuals from the Goyang collection for this study, but remains from the same time period and same province have been found to have an average male height of 161.4 cm and an average female height of 147.5 cm (Shin et al., 2012). Since the beginning of the 20th century, Korean stature has increased for each sex by a little bit more than a centimeter each decade with individuals of the 21st century averaging in height between 167.6 cm and 178.8 cm in males and 155 cm to 165.2 cm in females (Shin et al., 2012). While these findings only support a noticeable secular change in stature of the Korean population, they do suggest that other skeletal changes have occurred as South Korean society has since modernized and become industrial, causing the activities and lifestyle of modern Koreans to change also (Shin et al., 2012).

Three noticeable differences that could cause considerable secular change in Korean individuals are changes in diet, farming and cultivation techniques, and medicine. Of these three factors, improvement in farming and industry could have considerable effect when modern individuals are compared to the Goyang collection, especially the males, as most if not all pyungmin had a more physically demanding lifestyle such as farming, carpentry, or stone masonry (Choy, 1971), while the lack of industrialization of the period created a “self-sustaining” family economy where everything needed for daily living was produced by members of the household (Choy, 1971). This should be taken into consideration for future research as the environmental conditions of the Korean population have improved since the end of the Joseon dynasty, and have likely created secular changes in modern individuals.

Also, the Korean sample should be diversified further with other populations from continental Asia to better represent the ancestry of this region. Studies of Native Americans have highlighted that ancestral groups can be rather heterogeneous, and the assumption of homogeneity could decrease classification accuracy (Wescott and Srikanta, 2008). The two

Chinese study skeletons from UCF had mixed results, with one individual classifying with an accuracy of less than 50% and the other individual classifying with over 73% accuracy when all fifteen functions were tested. These differences in classification could be attributed to the greater robusticity of the first individual (HR-003) as well as genetic and environmental factors which were not accounted for in this study. However, the higher classification of HR-005 does present the possibility that the discriminant functions developed in this study could be applicable to other Asian ancestries. This is something that should be considered in future research of this postcranial method.

The factor of heterogeneity is present in the African ancestral population under analysis in this study which could have led to some of the misclassification of individuals in the African and European analysis, as it has in previous ancestral studies (Duray et al., 1999; Trudell, 1999). As the degree of heterogeneity could vary depending on the sample population the individual was from, it would be helpful to know exactly which individuals were used for each analysis be they from a modern or historical collection. However, since the same individuals were not used for each analysis and the sample sizes of each analysis fluctuate, it is hard to determine how much this could have affected results.

Lastly, discriminant analyses were conducted with individuals of both sexes and varying ages pooled together to make the largest possible sample size with the data available. Each group has a larger male than female population size, and this possibly could have skewed the results, particularly in the Korean population as the number of Korean males was twice that of Korean females. Understanding that the sex of an individual could increase classification of ancestry, various postcranial studies have been run to examine the degree sexual dimorphism in different ancestral populations contributes to correct classification (Dibennardo and Taylor, 1983; Baker et al., 1990; İşcan and Cotton, 1990; Wescott, 2005; Shin et al., 2012). However, because of the restricted number of individuals eligible for discriminant analysis based on measurement completeness, both sexes needed to be grouped together to create a larger sample for all three ancestral groups. As there are historical differences in activity between Korean males and females (Choy, 1971) and documented differences in average stature, it is likely that the osteometric sorting measurements for the Goyang collection would display some sexual dimorphism. Having larger samples sizes of each ancestral group, as well as a relatively equal sex distribution for each ancestry, could allow for this effect to be accounted for in future studies of all three ancestries.

Future Research

Despite the limitations of the present study, the classification rates from both parts of the discriminant function analysis suggest that osteometric sorting measurements can be used to differentiate ancestry successfully. The addition of other populations of Asian ancestry could make the resulting discriminant functions more applicable to the increasing Asian population of the United States. Not all Asian individuals are Korean, and so the current discriminant functions of this study should be used with caution when analyzing populations not included in the original analyses. The two Chinese skeletons from the University of Central Florida were analyzed using the Korean functions with positive results for individual HR-005 and less positive results for individual HR-003. The fact that HR-005 classified relatively well suggests that there are some underlying similarities between the geographical Asian ancestries, but HR-003 highlights the need for the functions used for analysis to be tailored to the individuals being classified. When the additional Asian ancestries are included in future analyses, the sample populations of each should be relatively large in size to better represent individuals from each geographical region and have similar numbers of males and females.

With a more equal distribution of the sexes, it would be easier to establish the influence sexual dimorphism has on measurements and ancestral classification. The current sample populations in this study have more males than females. This can skew the discriminant functions in favor of the larger male measurements and lead to higher misclassification of females. As the Koreans had the smallest measurements of all the ancestral groups analyzed, this may not cause as much of an issue in Korean females, but it could lead to the incorrect classifications of females of European or African ancestry. With the addition of other Asian ancestries, which may have measurements of smaller, similar, or larger size than the Korean sample population, the sexual dimorphism in the populations may play an even greater role in classification. Additional analyses should bring these variations within the populations to light.

African and European ancestry was represented by individuals from historical and modern collections which reduced the possible effects secular change may have on these populations during discriminant analysis. However, Korean ancestry was only represented by individuals from a historical collection. South Korea has changed since the end of the Joseon dynasty, and the health and nutrition of the modern population has improved (Shin et al., 2012). Each decade of the 20th century has shown an increase in stature, and so there is going to be some secular change between individuals today and the remains of the Goyang collection. The degree to which secular change will affect the osteometric sorting measurements and the bones that display the most significant differences could not be determined in this study. This is a factor that should be taken into account for when the Asian ancestry sample population is increased and diversified with every historical collection matched with a similar number of males and females from a more current collection of the same geographical region. This will allow for trends in the data and the size of measurements to be evaluated more thoroughly.

Each of the Korean osteometric sorting measurements was smaller than those of African or European ancestry. An examination of the mean z-scores for each individual's measurements further supported this size difference as the mean z-scores of most of the Korean population were found to be at least a half standard deviation below the group mean while individuals of African or European ancestry tended to have z-scores above the group mean. Knowing that size was a factor in ancestral classification, future studies also should examine the possible differences in shape between the three ancestries. The structure matrixes created during discriminant function analysis suggest a difference in the minimum diameter of the ulnar diaphysis (51A). Additional analyses could better illuminate whether the difference is related to a difference in shape, size, activity, or sexual dimorphism. It also could allow for conclusions to be drawn about the African and European measurements in regards to body proportions. With the utilization of all of these changes, future studies will make a promising postcranial method better fitted to the ancestral demographics of the United States and increase its forensic applicability.

APPENDIX A:
STATISTICALLY SIGNIFICANT OSTEOMETRIC SORTING MEASUREMENT DEFINITIONS

STATISTICALLY SIGNIFICANT OSTEOMETRIC SORTING MEASUREMENT DEFINITIONS

(Adapted from Adams and Byrd, 2010)

Many of the measurements found to be significant are minimum diameters, maximum diameters, and maximum lengths of skeletal elements that can be taken along, near a specific morphological feature, or of the entire skeletal element. As such, no images could be provided to depict the collection of these measurements as they differ from individual to individual. However, measurements taken at a specific location on a skeletal element are defined pictorially.

Clavicle

37B. Breadth at the Inflexion Point at the Distal End: Anchor the caliper in the concave curve of the inflexion point at the distal end of the clavicle and place the other jaw of the caliper on the opposite side usually on or near the tubercle (Figure 11).

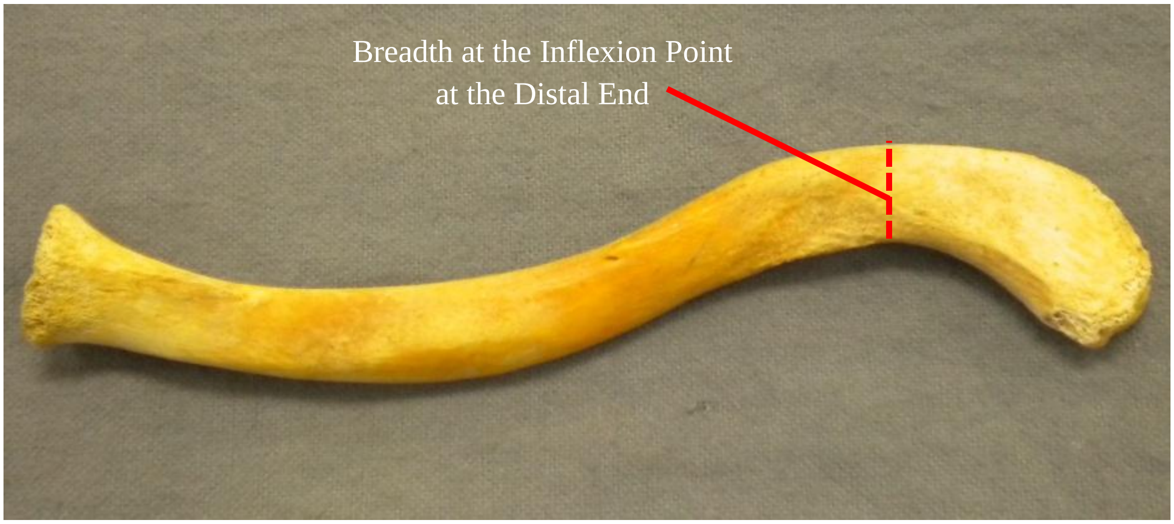

Figure 11. Superior view of the clavicle depicting osteometric sorting measurement 37B, the breadth at the inflexion point at the distal end.

37D. <u>Maximum Width at the Proximal End</u>: The maximum width of the short axis of the oval at the proximal end (Figure 12).

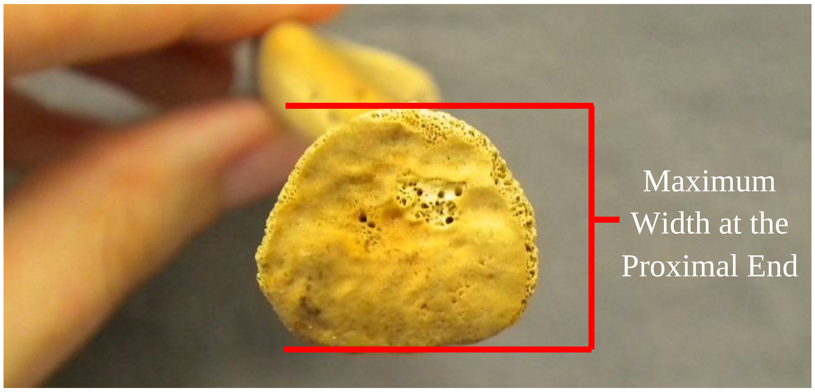

Figure 12. View of the proximal end of the clavicle depicting osteometric sorting measurement 37D, the maximum width at the proximal end.

Scapula

39A. <u>Maximum Length of the Glenoid Fossa</u>: The maximum length of the glenoid fossa. The measurement is taken on the articular margin of the fossa. Often a distinct rim is visible (look at the fossa from the side and take the measurement at the apex of the ridges). The maximum length is generally superior-inferior (Figure 13).

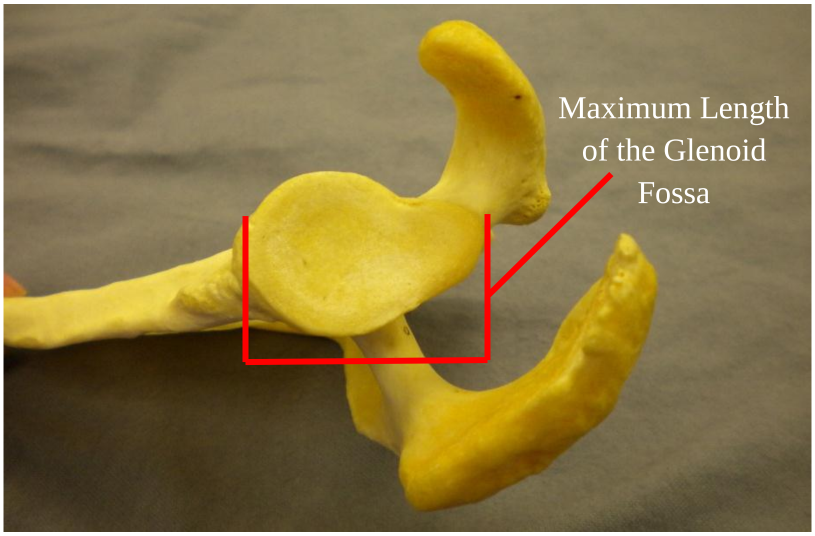

Figure 13. Lateral view of the scapula depicting osteometric sorting measurement 39A, the maximum length of the glenoid fossa.

Humerus

41A. <u>Total Breadth of the Capitulum-Trochlea</u>: The breadth of the capitulum and trochlea at the distal humerus. One end of the sliding calipers is positioned parallel to the flat, spool-shaped surface of the trochlea, and the other end is moved until it comes into contact with the capitulum (Figure 14).

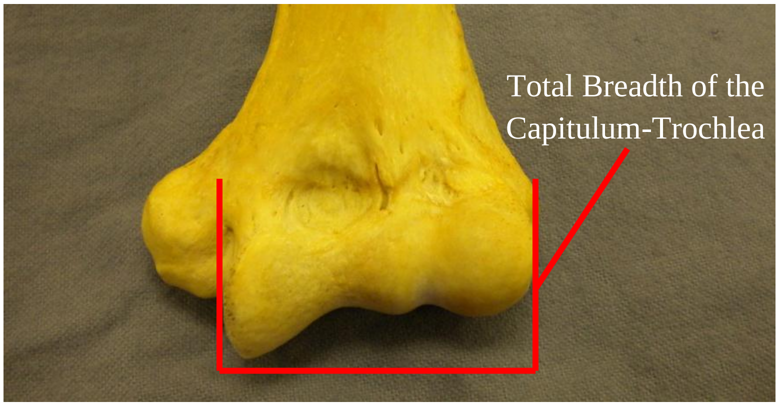

Figure 14. Anterior view of the distal end of the humerus depicting osteometric sorting measurement 41A, the total breadth of the capitulum-trochlea.

42A. <u>Anterior-Posterior Breadth of the Head</u>: The maximum breadth of the humeral head taken in the anterior-posterior direction on the articular surface. This measurement is taken perpendicular from the vertical diameter of the humeral head (42) (Figure 15).

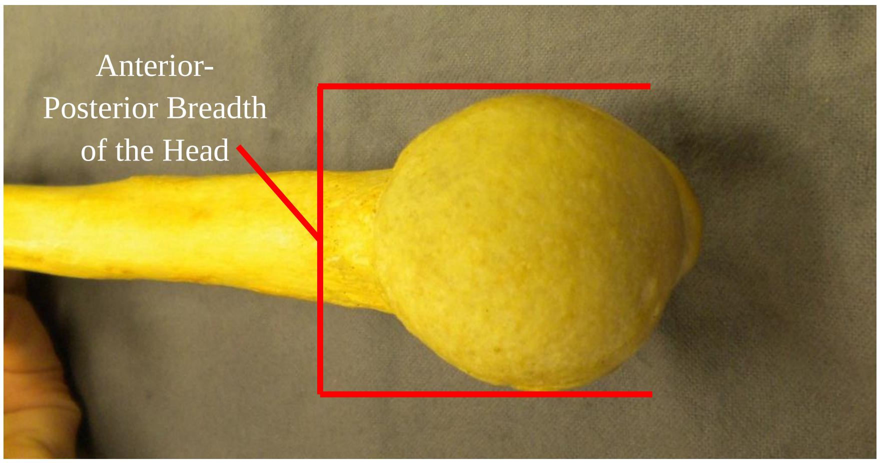

Figure 15. Medial view of the proximal end of the humerus depicting osteometric sorting measurement 42A, the anterior-posterior breadth of the head.

44B. Minimum Diameter of the Diaphysis: The minimum diameter of the humeral diaphysis taken in any direction perpendicular to the shaft. This measurement should be taken on the oval part of the shaft, superior to the flattening observed around the olecranon fossa and the lateral supercondylar ridge. Often it is near midshaft.

Radius

47B. Maximum Diameter of the Diaphysis Distal to the Radial Tuberosity: The maximum shaft diameter distal to the radial tuberosity, positioned along the interosseous crest. The bone should be rotated to find the maximum distance.

47C. Minimum Diameter of the Diaphysis Distal to the Radial Tuberosity: The minimum shaft diameter anywhere distal to the radial tuberosity. The bone may be rotated to find the minimum distance.

47D. Maximum Diameter of the Head: Position the calipers around the radial head and rotate the bone until the maximum distance is obtained.

47E. Breadth of the Distal Epiphysis: The maximum distance from the ulnar notch to the lateral aspect of the styloid process. The medial protrusions (articular borders of the ulnar notch) are placed against the vertical endboard of the osteometric board (sliding calipers may also be used) and the movable portion is applied to the lateral surface of the styloid process to find the maximum breadth (Figure 16).

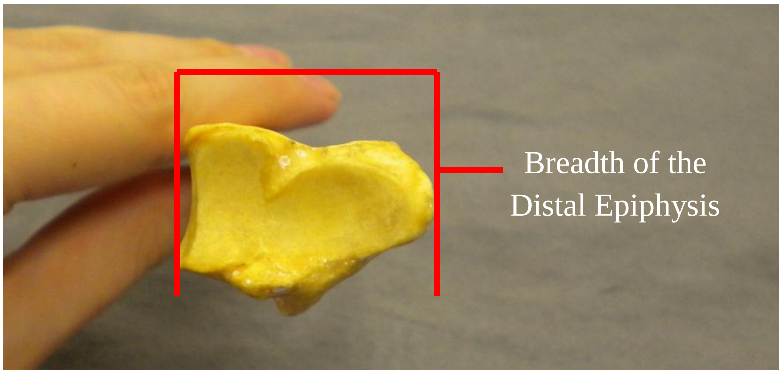

Figure 16. Distal end of the radius depicting osteometric sorting measurement 47E, the breadth of the distal epiphysis.

Ulna

51A. <u>Minimum Diameter of the Diaphysis, including the Interosseous Crest</u>: Locate the minimum diameter of the diaphysis along the portion of the bone that includes the interosseous crest. This measurement may not necessarily include the interosseous crest but should be taken on that part of the shaft that exhibits the crest. This measurement is not always near the distal end of the crest.

51B. <u>Minimum Diameter of the Diaphysis</u>: This measurement will be found near the distal epiphysis of the ulna. The bone should be rotated in order to locate the minimum distance.

Hand

52.5A. <u>Maximum Length of the 1st Metacarpal</u>: This is the maximum length of the bone. The measurement may be taken with an osteometric board or sliding calipers. Move the bone up, down, and sideways in order to obtain the maximum distance in the same manner that maximum length is obtained for the humerus, femur, etc.

52.5B. <u>Maximum Length of the 2nd Metacarpal</u>: This is the maximum length of the bone. The measurement may be taken with an osteometric board or sliding calipers. Move the bone up, down, and sideways in order to obtain the maximum distance in the same manner that maximum length is obtained for the humerus, femur, etc.

52.5C. Maximum Length of the 3rd Metacarpal: This is the maximum length of the bone. The measurement may be taken with an osteometric board or sliding calipers. Move the bone up, down, and sideways in order to obtain the maximum distance in the same manner that maximum length is obtained for the humerus, femur, etc.

52.5D. Maximum Length of the 4th Metacarpal: This is the maximum length of the bone. The measurement may be taken with an osteometric board or sliding calipers. Move the bone up, down, and sideways in order to obtain the maximum distance in the same manner that maximum length is obtained for the humerus, femur, etc.

52.5E. Maximum Length of the 5th Metacarpal: This is the maximum length of the bone. The measurement may be taken with an osteometric board or sliding calipers. Move the bone up, down, and sideways in order to obtain the maximum distance in the same manner that maximum length is obtained for the humerus, femur, etc.

Sacrum

55J. Maximum Breadth with the Osteometric Board: Position the sacrum on the osteometric board and find the maximum breadth of the alae (Figure 17).

Figure 17. Posterior view of the sacrum depicting osteometric sorting measurement 55J, the maximum breadth with the osteometric board.

Innominate

59D. Minimum Breadth of the Ilium from the Sciatic Notch: Position one end of the calipers in the sciatic notch and place the opposing jaw in the concavity either above or below the anterior inferior iliac spine (AIIS) to find the minimum distance. The measurement will usually be taken inferior to the AIIS. Once the jaws of the calipers are in a concavity bordering the AIIS, move the opposing jaws within the sciatic notch to find the minimum distance (Figure 18).

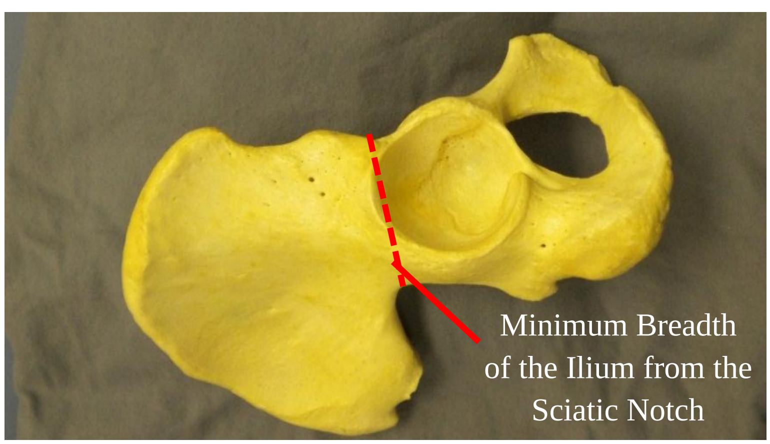

Figure 18. Lateral view of the innominate depicting osteometric sorting measurement 59D, the minimum breadth of the ilium from the sciatic notch.

59E. Maximum Diameter of the Acetabulum: The maximum distance of the acetabulum taken at any two points along the articular border of the lunate surface (look at the acetabulum from the side and take the measurement at the peaks of the ridges). This distance is commonly found in line with the iliac crest and the ischial tuberosity.

Femur

68A. Minimum Anterior-Posterior Diameter of the Diaphysis: The minimum anterior-posterior diameter anywhere along the diaphysis. The linea aspera and condyles should be utilized in order to orient the bone.

68D. Minimum Superior-Inferior Neck Diameter: The minimum distance from the superior surface to the inferior surface on the femoral neck (Seidemann et al., 1998) (Figure 19).

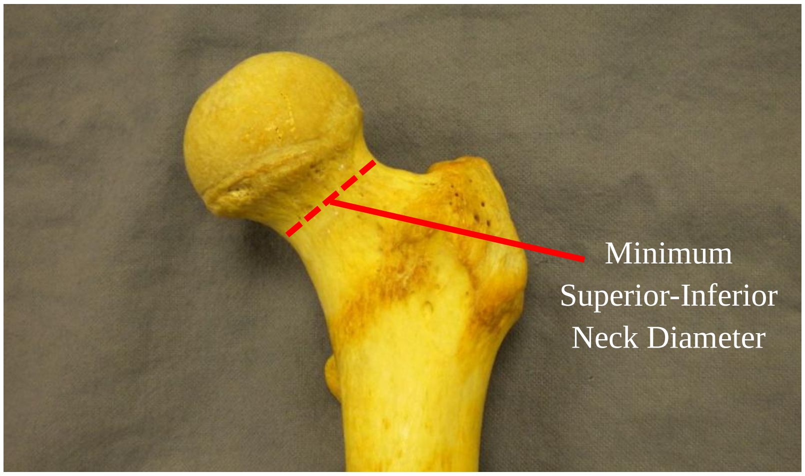

Figure 19. Anterior view of the proximal end of the femur depicting osteometric sorting measurement 68D, the minimum superior-inferior neck diameter.

Tibia

74A. Maximum Anterior-Posterior Diameter Distal to the Popliteal Line: This measurement should be taken at the most distal point of the popliteal line where it intersects with the margin of the diaphysis. The calipers are rotated to find the maximum distance (this is the maximum diameter of the diaphysis at this point). Note that the correct location may be difficult to determine in very gracile individuals (Figure 20).

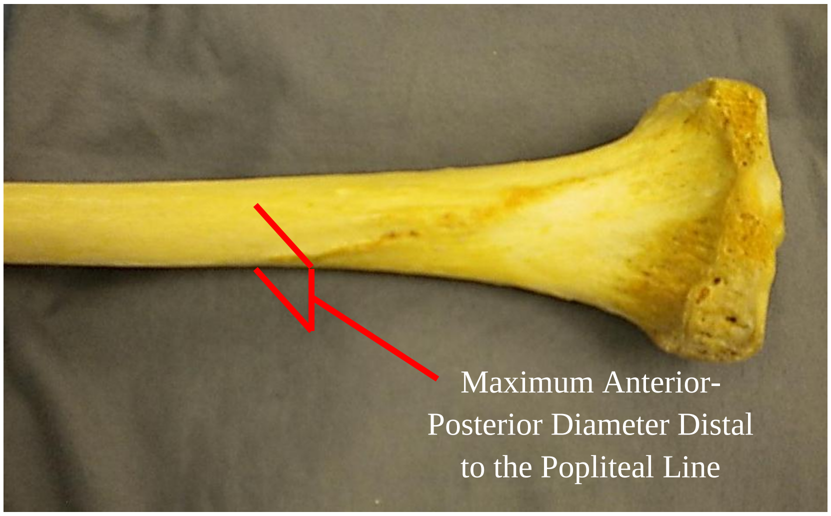

Figure 20. Posterior view of the proximal end of the tibia depicting osteometric sorting measurement 74A, the maximum anterior-posterior diameter distal to the popliteal line.

74F. <u>Maximum Anterior-Posterior Distance of the Distal Articular Surface</u>: Locate the maximum anterior-posterior distance of the distal articular surface by viewing the element from the side to find the peaks of the articular surface and measuring the distance between them. Use the medial malleolus to orient the bone (Figure 21).

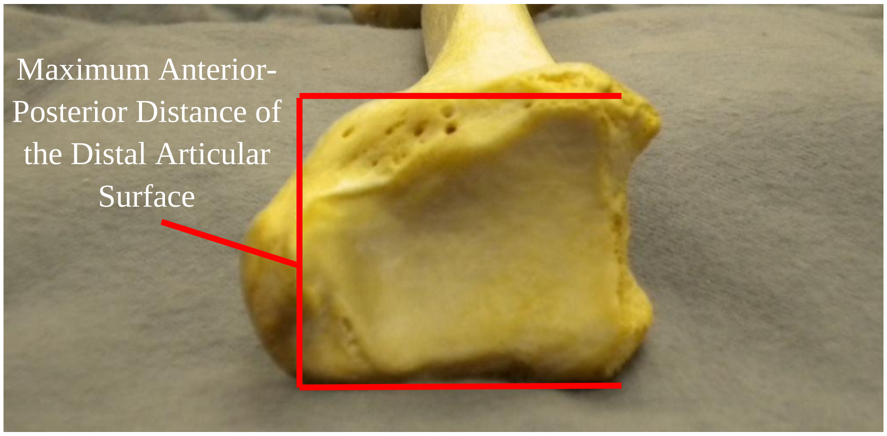

Figure 21. Distal end of the tibia depicting osteometric sorting measurement 74F, the maximum anterior-posterior distance of the distal articular surface.

Patella

74.5B. <u>Maximum Breadth</u>: Find the maximum breadth of the patella (Figure 22).

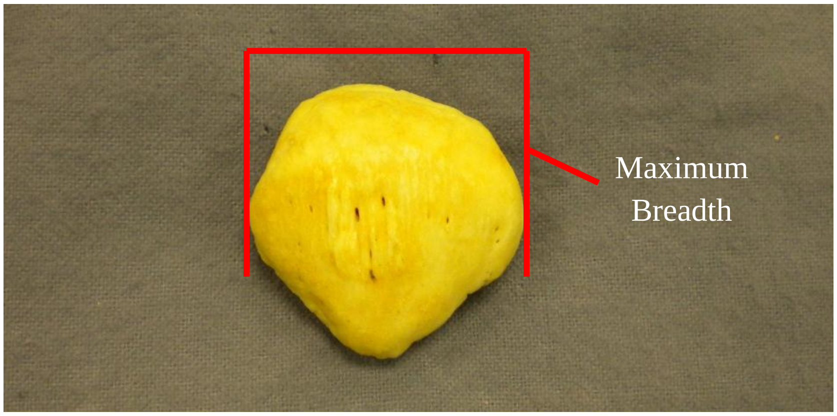

Figure 22. Anterior view of the patella depicting osteometric sorting measurement 74.5B, the maximum breadth.

Fibula

76A. <u>Maximum Diameter of the Diaphysis</u>: This measurement should be taken only along the interosseous crest (avoid measurements of the shaft near the epiphyses).

76C. <u>Maximum Breadth at the Distal End:</u> Place the one jaw of the caliper on the posterior portion (tubercle) and extend the other jaw to the opposite side (just above the malleolar articular surface) to find the maximum distance (Figure 23).

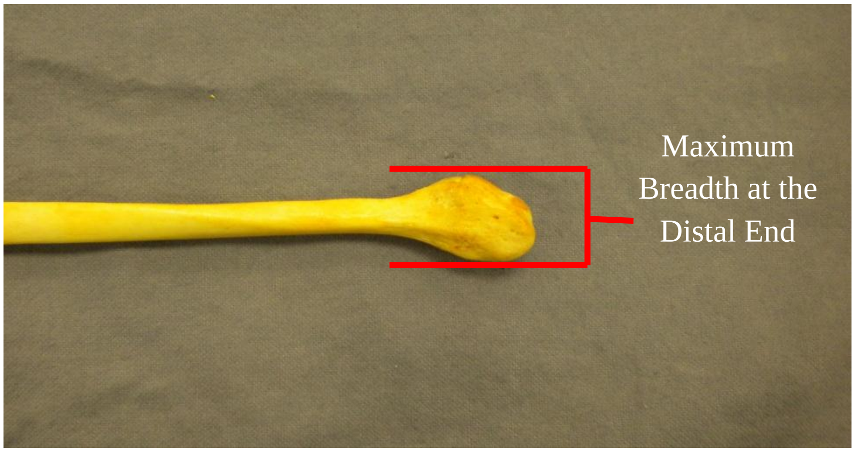

Figure 23. Lateral view of the distal fibula depicting osteometric sorting measurement 76C, the maximum breadth at the distal end.

Calcaneus

78A. <u>Minimum Breadth (Height) Distal to Articular Facets:</u> Find the minimum height in the pinched area of the calcaneus distal to the articular facets and proximal to the calcaneal tuber (Figure 24).

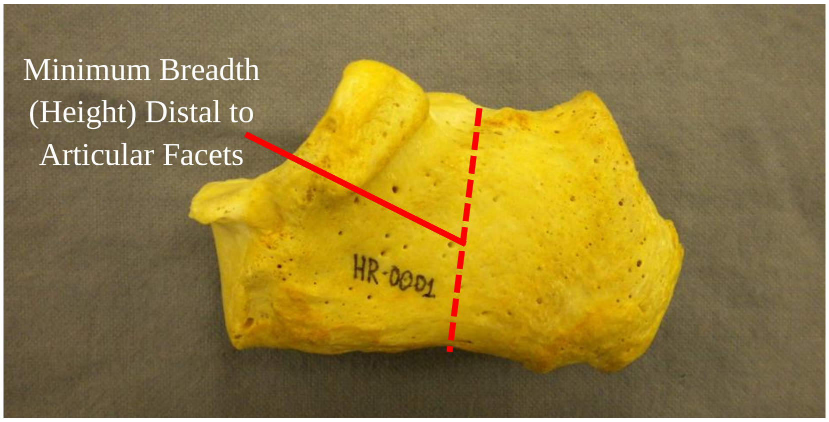

Figure 24. View of the calcaneus depicting osteometric sorting measurement 78A, the minimum breadth (height) distal to articular facets.

78B. <u>Posterior Length</u>: The maximum length between the most anterior point of the posterior talar articular surface and the most posterior point of the calcaneal tuberosity (Holland, 1995) (Figure 25).

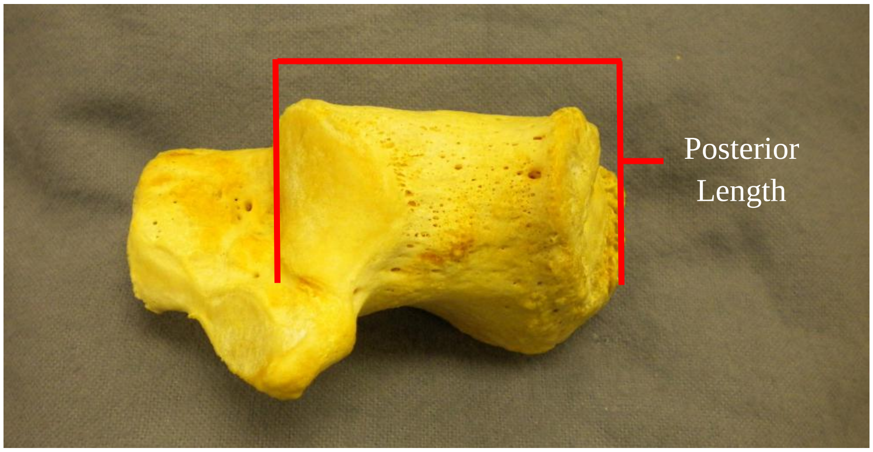

Figure 25. Dorsal view of the calcaneus depicting osteometric sorting measurement 78B, the posterior length.

Talus

79A. <u>Maximum Length</u>: The maximum length between the most anterior point of the head and the posterior tubercle (Holland, 1995) (Figure 26).

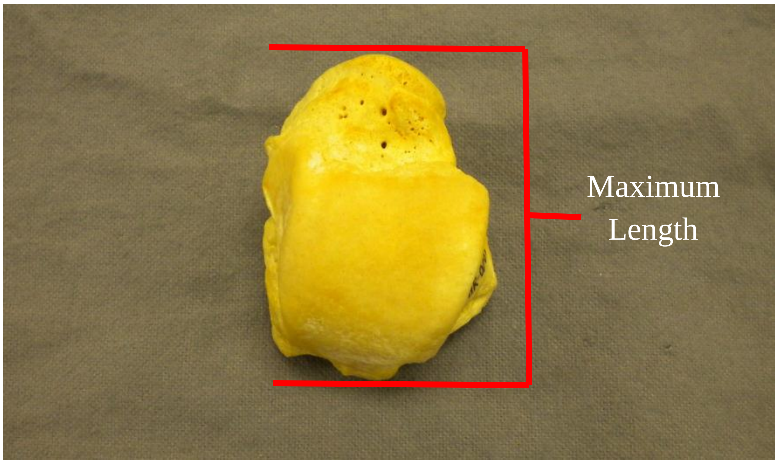

Figure 26. Dorsal view of the talus depicting osteometric sorting measurement 79A, the maximum length.

Foot

80B. <u>Maximum Length of the 2nd Metatarsal</u>: This is the maximum length of the bone. The measurement may be taken with an osteometric board or sliding calipers. Move the bone up, down, and sideways in order to obtain the maximum distance in the same manner that maximum length is obtained for the humerus, femur, etc.

80C. <u>Maximum Length of the 3rd Metatarsal</u>: This is the maximum length of the bone. The measurement may be taken with an osteometric board or sliding calipers. Move the bone up, down, and sideways in order to obtain the maximum distance in the same manner that maximum length is obtained for the humerus, femur, etc.

80D. <u>Maximum Length of the 4th Metatarsal</u>: This is the maximum length of the bone. The measurement may be taken with an osteometric board or sliding calipers. Move the bone up, down, and sideways in order to obtain the maximum distance in the same manner that maximum length is obtained for the humerus, femur, etc.

80E. Maximum Length of the 5th Metatarsal: This is the maximum length of the bone. The measurement may be taken with an osteometric board or sliding calipers. Move the bone up, down, and sideways in order to obtain the maximum distance in the same manner that maximum length is obtained for the humerus, femur, etc.

80F. Maximum Length of the Cuboid: This is the maximum length of the bone. The measurement should be taken with sliding calipers. Move the bone up, down, and sideways in order to obtain the maximum distance.

80G. Maximum Length of the Navicular: This is the maximum length of the bone. The measurement should be taken with sliding calipers. Move the bone up, down, and sideways in order to obtain the maximum distance.

80H. Maximum Length of the 1st Cuneiform: This is the maximum length of the bone. The measurement should be taken with sliding calipers. Move the bone up, down, and sideways in order to obtain the maximum distance.

80J. Maximum Length of the 3rd Cuneiform: This is the maximum length of the bone. The measurement should be taken with sliding calipers. Move the bone up, down, and sideways in order to obtain the maximum distance.

APPENDIX B:
POSTCRANIAL DATA FOR KOREAN ANCESTRY

POSTCRANIAL DATA FOR KOREAN ANCESTRY

Upper Limb Measurements

Korean individuals measured from the Goyang collection												
Measurements	**1**	**20**	**2-37**	**2-43(좌)**	**2-45**	**2-49**	**2-6**	**3-13**	**3-14**	**3-15(N)**	**3-18**	**3-23**
37A	23.5	24	24	23	*	21	27	*	30	*	*	24.5
37B	18	16.5	17.5	17.5	17	14.5	17.5	15	17.5	17.5	16	15
37C	11.5	10	13.5	13	10.5	12	10.5	11.5	12.5	13	8	14.5
37D	17.5	*	22.5	*	21	19	17	*	22	*	17	19
39A	31.5	36	38.5	33	36	34	34	30	34.5	33	31.5	34
39B	23.5	28	31	25	30	25	24	22	29	25.5	20.5	24.5
39D	42	38	43.5	45	43.5	40.5	42	33.5	48.5	39.5	41	45.5
41A	38.5	44	44.5	41	45.5	42	39.5	36	46	43.5	*	40.5
42A	37	40	41.5	*	41	*	36	*	*	40.5	*	39
44B	15	16	19.5	16	18	16	15	15.5	17.5	17	16	15
44D	19.5	22	27	22	25	22	18.5	20.5	24	23	19	21.5
47A	15	18	18.5	16	19.5	16	16	16	18.5	18	14	16
47B	15	15.5	19	16	19.5	16.5	14	14	17	15.5	14	16
47C	9	11	12	11	11.5	10.5	9.5	10	10	11	9	10
47D	20	24.5	*	22	24	21.5	20	*	*	*	18	*
47E	*	33	36	30.5	32.5	29.5	31	28	31	*	*	30
51A	*	10.5	12	10.5	11.5	11	10	9.5	12	10.5	9.5	11
51B	*	9.5	11	9	10	9.5	9	9	10	10	8.5	9
51C	*	24.5	25	22	26	22.5	21	20	24	23.5	*	*

*Measurement could not be collected.

Korean individuals measured from the Goyang collection												
Measurements	**3-84**	**40(동)**	**44**	**4-B-1(N)**	**4-B-41**	**52**	**55**	**55(R)**	**6**	**75**	**86**	**97(북)**
37A	20	29	34	30	28.5	26.5	23	18	18	*	*	*
37B	15.5	16.5	21	20	16.5	21	14.5	14.5	16	17	18	17
37C	9.5	12.5	12.5	13	12	12	10	25.5	9.5	10.5	14.5	13
37D	15.5	20	24	21.5	*	*	16	19.5	20.5	*	24.5	*
39A	30	34.5	36	34	30	*	*	*	30.5	35	*	32
39B	21	27.5	28.5	25.5	23.5	*	*	*	25.5	25.5	*	22.5
39D	35.5	47	52.5	46.5	38.5	*	48	*	40.5	46	*	40.5
41A	35	42.5	43.5	40.5	39.5	42	38	42	39.5	41	42	36
42A	34	38	40.5	*	36	*	36	41	38.5	37	40	37
44B	14	16	20.5	18.5	14	16	15.5	17.5	16.5	14.5	20	13.5
44D	19	24	26.5	23.5	21.5	23	20	22.5	20	19	24.5	18.5
47A	14.5	17	19	20	17	17	16	18.5	15	16.5	18.5	16
47B	14	16.5	18.5	17	15.5	15	14	18	15	15.5	18	16
47C	9	11	11.5	11.5	9	11	10	11	11	10	12	9
47D	*	*	22.5	*	20	23	18	22	20	*	*	*
47E	26	32.5	33	29	28.5	34	27.5	32.5	30.5	*	33.5	28
51A	9.5	11	13	12	10	10	9	11	10.5	9.5	12	9.5
51B	9	10	10	11	9	9	8	10	9	*	9	9
51C	*	22	27	23	21.5	22.5	20.5	24	22	*	24.5	*

*Measurement could not be collected.

Hand Measurements

Korean individuals measured from the Goyang collection												
Measurements	**1**	**20**	**2-37**	**2-43(좌)**	**2-45**	**2-49**	**2-6**	**3-13**	**3-14**	**3-15(N)**	**3-18**	**3-23**
52.5A	40.5	42	48.5	43.5	45.5	41	41.5	39.5	42.5	48	39.5	42
52.5B	*	62.5	72	63	65.5	61	61.5	60.5	66	*	62	61
52.5C	*	62	72	64	63	58.5	60.5	60	66.5	*	59.5	59
52.5D	*	*	61	54	54	*	51.5	52	56	*	58	50
52.5E	47	48	56.5	50	51	48	47.5	45.5	52	*	47.5	47
52.5F	*	27	28	28	*	*	*	*	27	*	23	*
52.5G	*	21	22.5	21	*	*	*	*	*	*	17	18
52.5H	*	19.5	*	20	*	*	*	*	21	*	*	17
52.5I	*	14	*	*	*	*	*	*	*	*	*	*
52.5J	*	25	26.5	*	27	*	*	*	*	*	*	*
52.5K	*	20	*	*	20	*	*	*	*	*	*	*
52.5L	*	27	28.5	*	29	*	*	23	27	*	*	26
52.5M	*	25	*	*	26	*	*	*	*	*	*	*

*Measurement could not be collected.

Korean individuals measured from the Goyang collection												
Measurements	**3-84**	**40(동)**	**44**	**4-B-1(N)**	**4-B-41**	**52**	**55**	**55(R)**	**6**	**75**	**86**	**97(북)**
52.5A	40.5	45	45.5	44	40.5	50	*	44	44.5	*	*	41
52.5B	61	67	67	*	58	68	61	63	65	*	*	60
52.5C	62	66	64.5	62	55.5	66.5	60.5	61.5	63	*	*	59
52.5D	53	54	55	57	48.5	59	51	52.5	53.5	*	*	50
52.5E	49	53	51	52	46	55	48	50.5	51	*	*	48
52.5F	22	30	27	*	*	30	*	27.5	*	*	*	25.5
52.5G	*	*	*	*	*	21	*	21	*	*	*	18
52.5H	*	*	20	*	*	*	*	17	*	*	*	*
52.5I	*	*	*	*	*	*	*	13.5	*	*	*	*
52.5J	*	24	25	*	21	24	*	24.5	*	*	*	21
52.5K	*	*	*	*	*	21	*	20	*	*	*	*
52.5L	*	26	26.5	*	*	27.5	23.5	25	*	*	*	24
52.5M	*	26	27	*	*	25.5	*	24.5	*	*	*	*

*Measurement could not be collected.

Pelvis Measurements

Korean individuals measured from the Goyang collection												
Measurements	**1**	**20**	**2-37**	**2-43(좌)**	**2-45**	**2-49**	**2-6**	**3-13**	**3-14**	**3-15(N)**	**3-18**	**3-23**
55J	108	100	*	106	112	*	*	*	*	*	108	111
59A	21	21.5	24	24	27.5	23.5	20	22	24	25.5	24	24.5
59B	33	36.5	40.5	36.5	39.5	36	35.5	36	38	40	37.5	34
59C	15.5	*	13	13	15	15	12	16	*	16.5	10	12
59D	55.5	59	62.5	57	60.5	61	56.5	57.5	70	60.5	61	58
59E	52.5	58	59	53.5	57	54	51.5	48	58	56	52.5	55

*Measurement could not be collected.

Korean individuals measured from the Goyang collection												
Measurements	**3-84**	**40(동)**	**44**	**4-B-1(N)**	**4-B-41**	**52**	**55**	**55(R)**	**6**	**75**	**86**	**97(북)**
55J	105	*	114	109	112	113	*	107	116	*	*	113
59A	20	23.5	26	26	20.5	24	23	26.5	23	22	23	28
59B	33	37.5	38	38	33.5	38	37	39.5	34.5	38	36.5	36
59C	13	*	15	17	15.5	11.5	14	10.5	13.5	12	16.5	17
59D	54.5	57	63.5	68	52	63	55	61	55	61	67.5	58
59E	49.5	56	56.5	56	51.5	59.5	48	50.5	52.5	55	53	55

*Measurement could not be collected.

Lower Limb Measurements

Korean individuals measured from the Goyang collection												
Measurements	**1**	**20**	**2-37**	**2-43(좌)**	**2-45**	**2-49**	**2-6**	**3-13**	**3-14**	**3-15(N)**	**3-18**	**3-23**
68A	22	23	27	25	28.5	*	19	21	23.5	23	24.5	24
68B	25.5	27.5	27.5	26	28.5	*	23.5	26	29.5	26	23.5	23
68D	28.5	32.5	33	28	31	*	25.5	26	33	30.5	30.5	29.5
68E	30.5	31	33.5	30.5	34.5	*	30	28	36	31.5	27	28
74A	28	32	32	32.5	31	*	25	25	33	31	30.5	27
74B	23.5	25.5	26	24	28	*	20	25	27.5	22	23.5	20
74F	25.5	29	29	28	30	*	27	34	32	30	*	26
74.5A	36	43	41	*	*	*	36	*	*	43	41	*
74.5B	38	44.5	45	*	47	*	36	17	*	44	42	37
74.5C	17	19	20	*	20	*	17.5	*	*	20	20	16.5
76A	10	16	10.5	15.5	17	*	13	14.5	16.5	14.5	13	14.5
76B	7.5	9	16.5	9	9	*	7.5	7	8.5	8.5	7.5	7.5
76C	22	24	26	25	26	*	21	23.5	26	26.5	21	23.5

*Measurement could not be collected.

Korean individuals measured from the Goyang collection												
Measurements	**3-84**	**40(동)**	**44**	**4-B-1(N)**	**4-B-41**	**52**	**55**	**55(R)**	**6**	**75**	**86**	**97(북)**
68A	19.5	24.5	25.5	25	21.5	28	22.5	25	20	21	25	22.5
68B	22.5	26	28.5	28	27	29	25	23	26	24	26	22.5
68D	25	30	33	30	26	25	25	26.5	30	27.5	30.5	28
68E	28	31	33.5	32	30	33.5	28	28.5	29	28	32	29
74A	26	32	32.5	29.5	30.5	34	23.5	30	26	25.5	31	24.5
74B	21	24.5	26	25	25.5	24	19.5	21.5	21.5	22	24.5	21.5
74F	27	28	29.5	26.5	27	32	25	27.5	27	27.5	30	24
74.5A	35.5	41	43	*	*	46	*	42	38.5	*	*	34.5
74.5B	37.5	43	44	*	*	46	*	48.5	40.5	*	*	38
74.5C	16	19	20	*	*	21	*	22	18.5	*	*	17.5
76A	14	17.5	19	16.5	14.5	16.5	12	15	14.5	12.5	16.5	14.5
76B	8	8.5	10	9.5	7	7.5	8	8	8	7.5	9	8
76C	21	24	27.5	24	21	26	20	25	23.5	23.5	26.5	22.5

*Measurement could not be collected.

Foot Measurements

Korean individuals measured from the Goyang collection												
Measurements	**1**	**20**	**2-37**	**2-43(좌)**	**2-45**	**2-49**	**2-6**	**3-13**	**3-14**	**3-15(N)**	**3-18**	**3-23**
78A	31.5	36	40	37	38	*	31	34	36	38	34	35.5
78B	49.5	52.5	52	52	52.5	*	49	46	57	54.5	52	52.5
79	28.5	33.5	34.5	31.5	31	*	30	27.5	31	33	30	30
79A	46.5	60	60.5	*	57	*	53.5	52	56	*	56	58
80A	53	54.5	62.5	59.5	57.5	*	54.1	55.5	63	*	55	59.5
80B	62	65	76	70	71	*	64.5	66	*	*	*	*
80C	60	59.5	69	67	66.5	*	60.5	61.5	*	*	*	*
80D	61	*	70	66	66	*	59.5	61	*	*	*	*
80E	62	*	69	*	*	*	62	60	*	*	*	*
80F	33	38.5	38.5	40	38.5	*	37	*	*	*	34	36
80G	*	38	41	36.5	*	*	37	*	*	*	*	36
80H	33	40	40.5	*	39	*	*	34	*	*	34	40
80I	*	25.5	24.5	*	*	*	*	24	*	*	*	*
80J	*	28	28.5	28	28	*	*	*	*	*	*	*

*Measurement could not be collected.

Korean individuals measured from the Goyang collection												
Measurements	**3-84**	**40(동)**	**44**	**4-B-1(N)**	**4-B-41**	**52**	**55**	**55(R)**	**6**	**75**	**86**	**97(북)**
78A	31	38	37.5	33	29	40	*	37.5	36	34	*	33
78B	47.5	56	57	55	47.5	55	*	52.5	52	48.5	*	46
79	28	31	32.5	30.5	30	32	*	30	29.5	30	*	31
79A	48	55.5	54.5	54.5	51	58.5	*	54	55	52	*	*
80A	53	62	60	60.5	54	64	*	59	*	61	*	55
80B	*	74	71.5	71	62	77	*	69.5	71	69	*	*
80C	*	70.5	67	66.5	57	72.5	*	66.5	*	*	*	*
80D	*	69	65.5	*	*	70	*	64.5	*	62	*	*
80E	*	74	65.5	*	60	76	*	66.5	62	66	*	*
80F	*	37.5	37	*	34.5	41.5	*	38	*	40	*	33
80G	*	43	43.5	*	*	*	*	42.5	35	39	*	34
80H	*	39.5	42	*	*	39.5	*	40	36	38	*	35
80I	*	26	*	*	*	25.5	22	25	*	*	*	*
80J	*	28.5	*	*	*	*	24	27.5	*	*	*	26

*Measurement could not be collected.

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